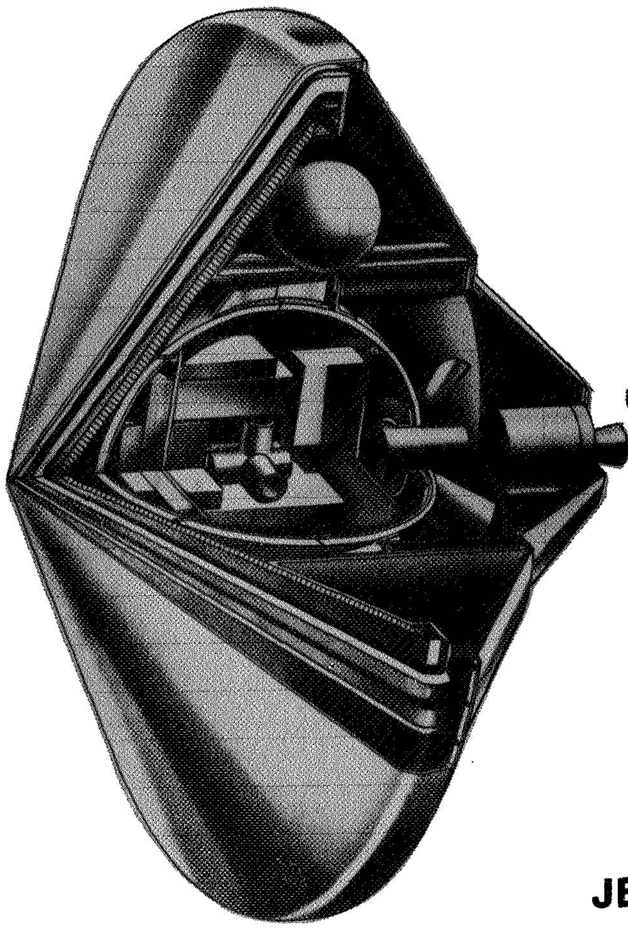
N71-38563

A STUDY OF A JUPITER ATMOSPHERIC ENTRY PROBE MISSION

FINAL REPORT
MANAGEMENT SUMMARY



1971 AUGUST 13

PREPARED FOR
JET PROPULSION LABORATORY
PASADENA, CALIFORNIA

PREPARED BY

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A STUDY OF A JUPITER ATMOSPHERIC ENTRY PROBE MISSION

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VOLUME I
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AVSD-0372-71-RR

1971 August 13

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Contract NAS7-100 JPL 952897

FOREWORD

This report contains the results of a study of a Jupiter atmospheric entry probe mission. The purpose of the study was: 1) to screen a large number of Jupiter entry probe missions, 2) generate configuration descriptions, and 3) identify both missions studies and technology developments that are worthwhile to enhance the feasibility and improve the success of the mission.

This Management Summary, Final Report, was prepared to provide a technical generalist or technical manager with a concise document that reports the major background, scope, and results of this study. A companion document, Technical Summary, Final Report was also prepared to provide the technical specialist with greater details and more supporting data.

A study was conducted to identify and describe feasible first-generation Jupiter atmospheric entry probe missions that have a large science return and that also tend to minimize engineering development. A principal groundrule for this study has been entry probe survival to the base of the cloud layers, with incorporation of electromagnetic sensors to permit remote sensing to greater depths. The major tradeoffs that were considered include 1) entry probe release from a 1978 and 1980 flyby trajectory, and from a 1979 Grand Tour trajectory, 2) use of a TOPS or Pioneer F/G spacecraft as an interplanetary bus, 3) direct and relay communication links, and 4) dayside and nightside entry into the atmosphere of Jupiter. The major results of the study indicated that 1) many feasible mission configurations are available, 2) use of remote sensing would extend the downward "reach" of the entry probe, and 3) there exist many useful science and technology development efforts that should be pursued to further the realization of Jovian atmospheric exploration.

ACKNOWLEDGEMENTS

The following personnel from the Avco Systems Division contributed to this study of a Jupiter atmospheric entry probe mission:

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1.0 INTRODUCTION AND SUMMARY

A study was conducted to screen and identify feasible Jupiter entry probe missions that achieve the science objectives, and that tend to minimize engineering development. A principal groundrule for this study has been entry probe survival to the base of the cloud layer with remote sensing to provide information at greater atmospheric depths. This approach to the study of a Jupiter atmospheric entry probe mission is significantly different than the equally valid approach of entry probe survival to great depths within the atmosphere with in situ sensing. For example, in the nominal Jovian model atmosphere the base of the cloud occurs at a pressure of 17 atm and the ambient temperature at this level is 425 deg K. Deep descent is considered to be at the 1000 atm level and the corresponding ambient temperature is 1425 deg K.

The approach taken to the study was to identify the key science tradeoffs and identify the key engineering tradeoffs. These tradeoff studies were used to uncover those missions that tend to combine good science and favorable engineering. Entry probe supporting systems and subsystem performance requirements were defined based on the favorable mission combinations. The results of configuration descriptions were used to indicate the necessary research and development that must be conducted to: enhance the science return, increase the allowable targeting boundaries, and increase mission success.

Study guidelines were provided to channel the technical effort and take advantage of projected program developments that would be anticipated to parallel the development of a Jupiter probe and be available for use, with this mission. In addition environmental guidelines were provided as well as mission operation guidelines. The principal guideline was the JPL science criteria and science complement. The science objectives for this mission include determination of: 1) the chemical and isotopic composition of the atmosphere, 2) thermal structure of the atmosphere, 3) composition and structure of the clouds, 4) existence of complex organic matter, and 5) nature of the coloring matter in the clouds. A set of instruments that could perform the required measurements to satisfy the science objectives were also provided. A key mission guideline was consideration of a probe system that would achieve the science objectives by descent to the vicinity of the base of the Jovian cloud layers. Another important mission guideline was consideration of 1978 and 1980 launch opportunities. For these launch opportunities, the trajectory targeting could be tailored to provide a set of planetary encounter conditions favorable to an entry probe. In addition, a 1979 launch opportunity was considered, but the trajectory targeting was consistent with the requirements for a Jupiter-Uranus-Neptune Grand Tour Mission. Two types of spacecraft were considered, i.e., a TOPS and a Pioneer F/G. The TOPS is a three-axis stabilized radioisotope powered spacecraft that weighs 1450 lb. During Jovian encounter, the high gain antenna is oriented towards Earth. The Pioneer F/G is a spin stabilized, radioisotope powered spacecraft that weighs 550 lb. At Jupiter encounter, the high gain antenna is directed towards Earth. A Titan III family of boosters were considered. The basic building block of this family of boosters is the two-stage Titan III D. Two solid rocket motors of either five or seven segments are provided as a zero stage. The third stage is a Centaur or higher performance Stretched Centaur, and the fourth stage is the Burner II or a higher performance fourth stage, the Versatile Upper Stage.

Jovian atmospheres were provided to bound the entry and descent environment. A nominal model was provided, and two bounding extremes, i.e., a high temperature extreme and a low temperature extreme. For this study, the high temperature extreme was termed the warm/expanded model atmosphere and the low temperature extreme was termed the cool/dense model atmosphere. A critical area of probe design and mission selection concerns the performance of the heatshield. For shallow angle entry in the direction of the rotation of Jupiter, the entry velocity is 160,000 ft/sec. This velocity is considerably advanced in terms of current analytical and test facility technology. Extrapolation of current heatshield technology to Jovian entry leads to thermal protection subsystem weight requirements that are two to three times greater than the entry probe system weight (without heatshield). Preliminary analysis of the thermal protection problem indicates that there exist self-limiting processes that block the transfer of energy to the probe and reduce the response of the ablator to the heat pulse. If the processes are considered, then the thermal protection subsystem weight requirements are only thirty to fifty percent of the entry probe system weight. Heatshield performance for Jovian entry was provided.

Identification of favorable missions and insight into Jovian mission limitations was gained by study of nine key mission tradeoffs which include: 1) science payload, 2) probe targeting, 3) model atmosphere, 4) depth of atmospheric descent, 5) launch opportunity, 6) interplanetary trajectory, 7) probe entry angle, 8) communication link, and 9) spacecraft.

It was determined that of the five science objectives, three are satisfied by probe descent through an in situ measurement in the clouds. These objectives include the composition and structure of the clouds, the existence (or absence) of complex molecules, and nature of coloring matter in clouds. Since all but heavy elements are volatile within the cloud layer, the objective of chemical and isotope composition can be substantially satisfied. To achieve the objective of thermal structure, the existence (or absence) of a thermal heat source must be determined, and mechanism for transport of energy from the interior to the clouds must also be determined. Remote sensing from a flyby can best resolve the question of a heat source. In situ measurements by a low resolution infra red photometer aboard the entry probe can provide data on the thermal structure of the clouds, and remote measurements by a wide band microwave radiometer aboard the probe can provide data on the thermal structure of the atmosphere below the clouds.

Many feasible missions were uncovered. The underlying physical constraint that focused the selection of system parameters was the peculiar targeting geometry for Jupiter and the outer planets. From a science point of view, dayside entry is valuable, because it allows for use of photometer instruments aboard the probe that use the sun as energy source. Dayside entry can be achieved by a long time of flight and shallow angle entry and also by a short flight time and steep probe entry. From an engineering point of view, short flight times are desirable to improve shelf life reliability whereas shallow angles are desirable to reduce the weight of the aeroshell structure and thermal protection system. The one science and two engineering goals of: dayside entry, high reliability, and high payload mass fraction are controlled by flight time and entry angle, and the required combination to satisfy all the goals, of shallow entry angle and short flight time is not available. For this study, shallow entry angle and long flight time approach was followed. This is based on the belief that long shelf life is a simpler development problem in comparison with development of subsystems to withstand high G, and development of a heatshield to protect against the more severe heating environment that are associated with steep entry angle.

Probe descent to the base of the cloud layer in both the nominal and cool/dense model atmospheres is feasible. However, the descent through the nominal model atmosphere both direct and relay communication links are feasible whereas in the cool/dense model atmosphere, only a low frequency (UHF) relay communication link is possible. This limitation to direct link is caused by the fact that the lower lapse rate in the cool/dense model atmosphere permits clouds to persist to high pressure levels. The cloud base in the cool/dense model atmosphere is at 525 atm, and in the nominal model atmosphere, at 17 atm. The principal contribution to R. F. propagation losses is the ammonia gas constituent of the atmosphere, and at high pressure in the cool/dense model atmosphere the mass of ammonia per unit area along the communication line of sight is considerably greater than in the case of the nominal model atmosphere. It was also determined that entry into the cool/dense model atmosphere results in G loads that are more than a factor of two greater than the loads experienced during entry into the nominal model atmosphere. These higher loads are caused by the lower scale height in the cool/dense model atmosphere and effective shorter atmospheric path length for entry probe deceleration.

Both TOPS and Pioneer F/G spacecraft can serve as a bus for delivery of an entry probe, and both spacecraft can also serve as an uplink in support of a relay communication link mission.

Technology requirements have been identified and cataloged as: research requirements, critical technology requirements, and key technology improvement areas. A research requirement is defined as an area of improvement that is associated with the physical parameters of Jupiter. The research requirements include improvement in assessment of range of model atmospheres, and development of atmospheric wind and turbulence models. Model atmosphere improvement is valuable particularly if the cool/dense model is concluded to be too severe. Of the three model atmospheres, the cool/dense model provided all of the important system and subsystem design constraints. During conduct of the study, atmospheric wind influence on probe dynamics was factored into the communication link analysis. However, a more rigorous treatment is needed. In addition, atmospheric turbulence can lead to fluctuations in refractive index of the atmosphere and signal fading. Turbulence effects have not been accounted for. Also, improvement in the knowledge of the position of Jupiter would reduce the dispersions in probe performance, and result in a more efficient mission. A critical technology requirement is defined as an area of improvement that is associated with the engineering feasibility of the entry probe. Critical technology requirements that have been identified are: development of a thermal protection system for entry, development of subsystems to survive exposure to a high-G environment and operate in a high magnetic field and development subsystems with a long shelf life. A key technology improvement is defined as an advance in the state-of-the-art of a subsystem that will provide greater mission flexibility and/or performance. This study pointed up the need and value of lightweight steerable entry probe antennas and need for reduction in dispersions of the entry probe deflection maneuver to alter the entry probe trajectory from a flyby of Jupiter to an impact of Jupiter. This dispersion influences the entry probe entry angle and more important for a relay link, it influences the entry probe communication gain. The dispersion is comprised of errors in: uncertainty in knowledge of position of Jupiter, uncertainty in deflection motor impulse, and uncertainty in angle at which impulse is applied. Errors in impulse and angle are considered to be key technology improvement areas, whereas an error caused by position uncertainty is considered to be a research requirement.

2.0 SCOPE OF MISSION

The information contained in this section sets the scientific objectives, engineering guidelines, and the Avco Systems Division approach to the Jupiter atmospheric entry probe mission study. To help orient the reader, a section titled mission description is included to provide a total view of the mission characteristics.

2.1 SCIENTIFIC OBJECTIVES

The Jupiter atmospheric entry probe science objectives were defined by JPL in terms of a set of questions. These scientific questions that could be investigated by a first-generation entry probe are:

1) What are the relative abundances of hydrogen, deuterium, helium, neon, and other elements, and what are their isotopic compositions?
2) What are the present-day atmospheric composition and altitude profiles of pressure, temperature, and density, and what effect do they have on the radiation balance?
3) What are the chemical composition and vertical distribution of the clouds?
4) Do complex molecules exist in the atmosphere of Jupiter?
5) What are the nature and origin of the colors observed in Jupiter's atmosphere?

One of the goals of this study has been to investigate the feasibility of achievement of these science objectives from an entry probe that is designed to survive to the base of the cloud layer.

Certainly objective 3), chemical composition and vertical distribution of the clouds, and objective 5), nature of coloring matter in the clouds can be satisfied by probe descent to the base of the clouds. Since the production of complex molecules requires an energy source such as solar UV light and/or lightning, and since lightning is generated within the cloud layers and UV light is absorbed within the cloud layers, science objective 4) can also be satisfied by a probe that descends to the base of the cloud layer.

It has been determined that objective 1), chemical and isotopic composition of the atmosphere can be substantially achieved by a probe that descends to the base of the cloud layers. Compounds or the elements of hydrogen, helium, carbon, nitrogen, oxygen, neon, sulfur and argon can exist over the local temperature and pressure conditions that are to be found within the cloud layers. That most components of the lighter elements can be found within the cloud layers is, in part, a consequence of the same physical phenomenon that permits the formation of clouds i.e., the same vapor pressure - temperature physical data that allows volatility of compounds also will permit the formation of clouds. Compounds of heavier elements like silicon, magnesium, and iron are non-volatile at temperatures less than 1500 to 2000 deg K. In the nominal model atmosphere this temperature range occurs at atmospheric pressure levels that exceed 1000 atm.

Of all of the science objectives, only objective 2), the thermal structure of the atmosphere cannot be totally determined by a direct measurement. A qualitative assessment of the problem has indicated that a combination of in situ sensing during descent through the clouds are remote sensing following emergence from the cloud base can provide the information needed to satisfy this science objective. This science objective can be divided into two separate areas of investigation. First, it is important to determine whether or not an internal heat source exists within the planet, and the second area for investigation is determination of the mechanism for transport of energy from the interior of the atmosphere to the clouds. The easiest way to resolve whether or not an internal heat source exists is to observe the total radiant flux emerging from Jupiter over the thermal wavelength region. This requires either a wide-band infra-red radiometric measurements or numerous high-resolution infra-red photometry measurements at wavelengths within the thermal radiation region. Ideally, the measurements should span all phase angles, so that a possible anisotropy in the radiation field could be detected and allowed for. This type of measurement is ideally suited from a Jovian flyby or orbiter spacecraft. The second part for achievement of this objective must be conducted aboard the entry probe. It is necessary to provide instrumentation to make measurements that permit determination of the lapse rate in the clouds and in the interior. For example, a zero lapse rate below the clouds will imply that the atmosphere is isothermal and that the mechanism for the transport of thermal energy is radiation. A subadiabatic lapse rate would indicate that some combination of radiation and convection is available for transport of energy. The existence of a superadiabatic lapse rate would indicate that there exists mass motion of the atmosphere, and transport of thermal energy by the phenomenon of convection is dominent. The thermal structure of the cloud layers can be determined by in situ measurement, whereas the thermal structure of the interior must be inferred by remote sensing. By providing microwave radiometers that look towards the zenith and nadir, it is possible to determine the downward microwave brightness temperature and correct for the effects of microwave opacity of the atmosphere. From this remote brightness temperature and in situ temperature, pressure, and composition measurements, it is possible to infer the downward lapse rate and hence the thermal structure and mechanism of energy transport.

2.2 MISSION DESCRIPTION

A typical Jupiter probe mission profile is shown in Figure 1. The flight time to Jupiter for the launch opportunities of interest for this study, i.e., 1978, 1979, and 1980 can range from 450 to 1450 days. Both TOPS and Pioneer F/G spacecraft can serve as a bus for the probe. The entry probe which is attached to the bus is injected onto the required interplanetary trajectory by a Titan III D launch vehicle. A nominal launch vehicle configuration is: 1) the Titan III D which is a two stage vehicle and provides the first and second stage of propulsion, 2) two, five segment zero stage solid rocket motors, 3) the Centaur D-1T as third stage, and 4) the Burner II as fourth stage. During the interplanetary cruise all electrical, communication, and thermal requirements are provided by the bus.

Near the sphere of influence at a range of about forty-five million kilometers from Jupiter the probe is separated from the bus, and an impulse is provided to deflect the entry probe which is on a Jovian flyby trajectory with the bus, to a planetary impact trajectory. Probe deflection attitude information is provided by the bus spacecraft. Two types of separation are possible. Either the spacecraft can conduct an attitude maneuver to align the probe propulsion system in the proper orientation prior to release of the entry probe or the spacecraft can impart attitude information to a probe attitude reference subyssstem so that after separation the probe can maneuver to the proper orientation for application of impulse. Coast time from separation to planetary entry can range from thirty to sixty days and depends on the value of the hyperbolic approach velocity of the selected interplanetary trajectory. During the post separation cruise the entry probe is conducting magnetic field measurements and ion mass spectrometer measurements. About thirty minutes prior to entry, the meteoroid container is separated.

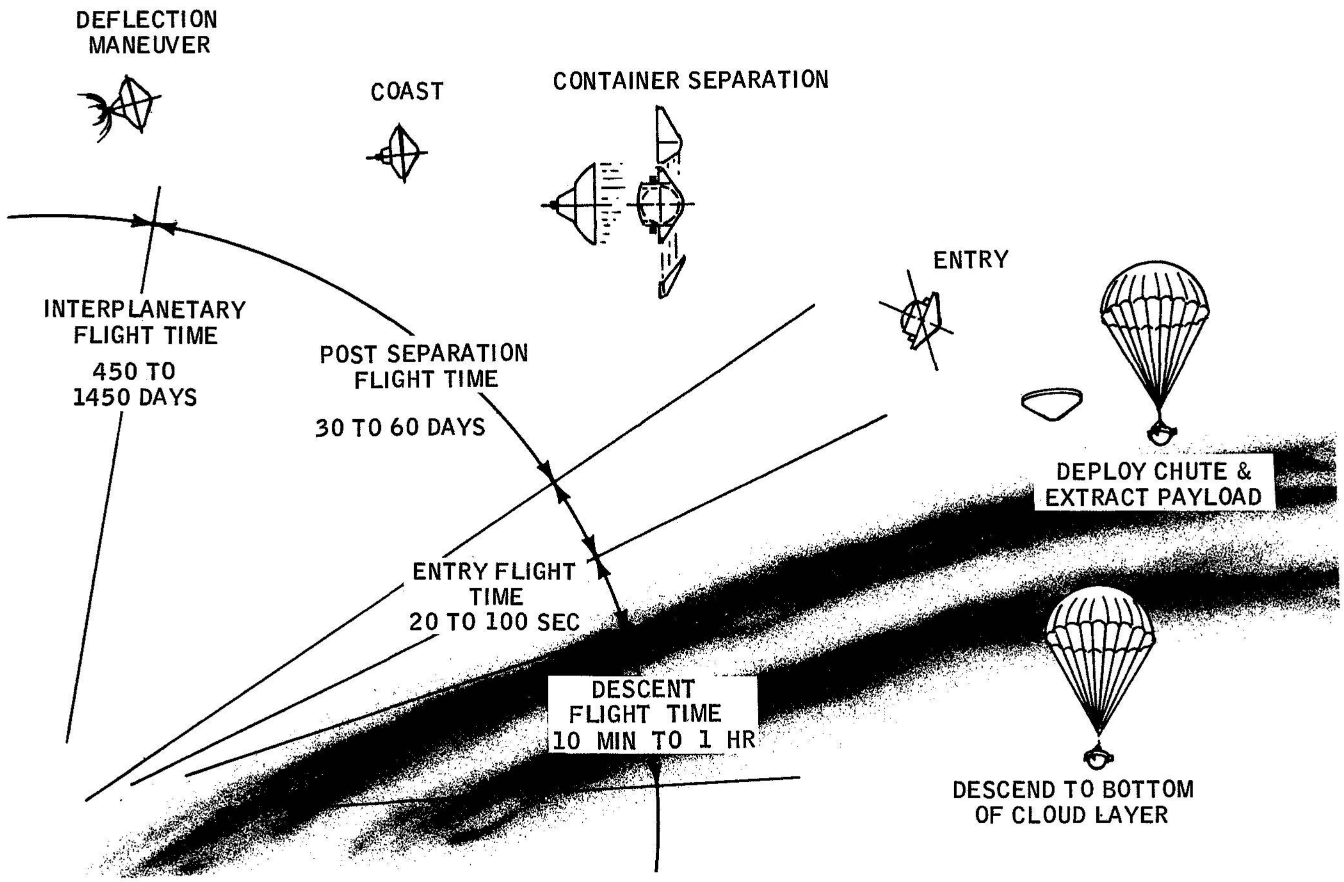

Figure 1 TYPICAL JUPITER PROBE SEQUENCE OF EVENTS

Prior to entry, the probe angle of attack is nulled. Attitude information can be gained from a ion sensor prior to entry or transverse accelerometers immediately prior to entry. Entry is defined to be a 0.1G output from the longitudinal accelerometer. One minute of ion mass spectrometer data is stored prior to 0.1G. The entry probe decelerates to subsonic velocity (0.7 Mach No.) in 20 to 100 seconds, depending on whether the entry angle is steep or shallow. During deceleration, the accelerometer output is stored, and retransmitted following emergence from communication blackout. At 0.7 Mach No., the parachute is deployed and extracts the subsonic configuration which contains the payload from the aeroshell structure and heatshield. The probe descends on chute through the clouds, sampling the atmosphere, and telemetering data. For some missions, the parachute is separated after passage through the water clouds, to decrease the descent time to descend through the lowest cloud layer, the ammonium chloride clouds. During this descent, the aerodynamic shape is that of a sphere that has been aerodynamically stabilized by addition of a torus just past the maximum diameter of the sphere. The mission is completed shortly after the probe reaches the base of the cloud layers and enters the clear lower region of the Jovian atmosphere descent time through the clouds can range from about 10 minutes to one hour.

2.3 STUDY GUIDELINES

The following system and environmental guidelines were provided by JPL to ensure that 1) the broad scope and range of necessary tradeoffs of this study were understood, 2) the most up to date Jovian environmental data was available, and 3) the most up to date information on parallel programs that would support the entry probe mission was also available.

a) Depth of Atmospheric Descent

The probe shall be instrumented and designed so that it can achieve the science objectives by in situ sensing during descent through the cloud layers, and remote sensing during and immediately following emergence from the base of the clouds.

b) Science Criteria

The five Jovian scientific objectives for an entry probe mission was provided as well as a sample payload of instrumentation, termed JPL baseline payload. The payload is designed for a probe that descends to the 1000 atm pressure level.

c) Mission Opportunities

Both 1978 and 1980 launch opportunities with a flyby trajectory tailored to an entry probe mission, and a 1979 launch opportunity with a flyby trajectory tailored to the requirements of a Grand Tour Mission. JPL-generated interplanetary trajectory data, and astrodynamic constants were provided.

d) Jovian Environment

A Jovian environmental handbook was provided. The principal environmental factors which were of concern for this study were the model atmospheres, the model magnetic field strength, and the model trapped radiation belts. These model atmospheres were the most important environmental constraints. Three models were provided: a warm/expanded model atmosphere, a nominal model atmosphere, and a cool/dense model atmosphere. This nominal model atmosphere was used as the basis of comparison for the influence on design of the bounding extremes.

e) Forebody Heatshield Weight

The variation of forebody heatshield weight for a 60 deg half-angle sharp cone was provided as a function of entry angle and ballistic parameter. Also provided were tables that would permit estimates of heatshield thickness at four different stations. A chart was given that showed the normalized heatshield loss as a function of normalized deceleration velocity profile.

f) Bus Spacecraft System Descriptions

Preliminary descriptions of both TOPS and Pioneer F/G spacecraft were provided. The TOPS is a three-axis stabilized spacecraft that uses a radioisotope power source and weighs 1450 lb. The Pioneer F/G is a spin stabilized spacecraft that uses a radioisotope power source and weighs 550 lb. Both spacecraft have been designed for outer planet missions and have to be modified to serve also as an entry probe bus.

g) Launch Vehicle

The Titan III D/Centaur family of launch vehicles was used for this study. The first stage and second stage of the launch vehicle correspond to the two stages of the Titan III D. Two solid rocket motors of either five or seven segments serve as a zeroth stage. A Centaur or higher performance stretched Centaur is the third stage, and the Burner II or very high performance Versatile Upper Stage is the fourth and last stage. Two launch vehicle shrouds have been considered, i.e., a 12.5 ft. diameter dynamic shroud envelope, that is termed the Viking shroud, and a 10 ft. diameter dynamic shroud. The payload injection capability of the launch vehicle is based on use of a Viking shroud. If the smaller 10 ft. diameter shroud is used, then a small increase in payload injection weight can be realized.

h) Deep Space Net Capability

DSN capability was provided for three different modes of operation. From the point of view of greatest direct communication link performance, performance capability was given for a probe only mission which would only require an S-band receive mode at DSN. For a Pioneer F/G mission the DSN must not only receive at S-band but must also transmit at S-band, and the receive S-band performance is lower than for the case of receive S-band only. For a TOPS mission, the DSN must receive S-band and X-band and transmit S-band. The receive S-band performance is still lower than that for the Pioneer F/G mission.

i) System and Subsystem Performance Criterion

State-of-the-art as of 1975 was used in defining the performance of entry probe vehicle.

j) Planetary Quarantine

Planetary quarantine was not considered in this study.

2.4 STUDY APPROACH

The approach taken to this study was to first identify missions with good science return characteristics with respect to their ability to achieve the science objectives and to identify missions that tend to minimize engineering development. System level tradeoffs were conducted between these favorable science missions and favorable engineering missions, and many feasible and attractive missions were sifted out. A single mission was selected and served to define entry probe system and subsystem configurations. Description of the system and subsystem configurations and their requirements were used to identify the technology requirements that should be pursued to enhance the realization of a Jupiter entry probe mission. A study flow diagram is shown in Figure 2.

In Section 3.0, there is discussed the key science tradeoffs that were to identify mission with good science return. Section 4.0 covers the key engineering tradeoffs that were studied to minimize engineering requirements. In Section 5.0, there is presented a matrix of potential mission possibilities. Entry probe system and subsystem configurations are described in Section 6.0, and technology requirements are identified in Section 7.0.

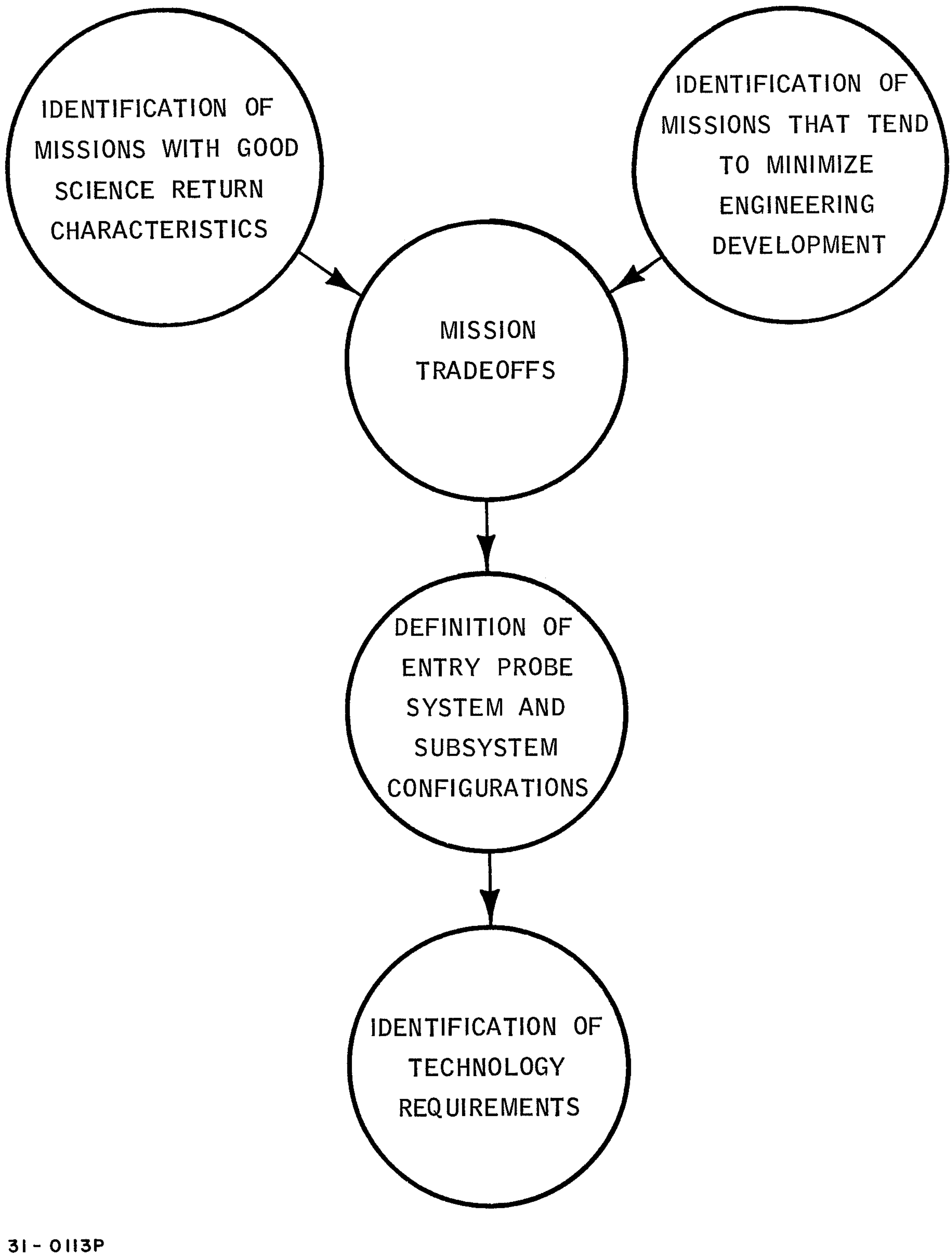

Figure 2 STUDY APPROACH

3.0 KEY SCIENCE TRADEOFFS

Four key tradeoffs were recognized for evaluation of the science return, and are shown in Figure 3. These tradeoffs include: 1) varying degrees of comprehensiveness of the science payload, 2) the lighting conditions at and during entry, 3) the Jovian model atmosphere, and 4) the depth of descent into the atmosphere.

3.1 SCIENCE PAYLOAD

Three science payloads were formulated to provide an opportunity to determine the sensitivity of: 1) entry probe design to changes in payload, and 2) achievement of science objectives to changes in payload. These payloads are termed the nominal payload, small payload, and expanded payload. Due to targeting restrictions and the impossibility of simultaneously satisfying short interplanetary transit time, shallow entry angle, and dayside entry, both dayside and nightside payloads were investigated for the three classes of entry probe payloads.

The JPL Jupiter entry probe baseline payload served as the initial science payload guide; the instruments that comprise this payload are indicated in Figure 4. A nominal dayside payload was defined based on the philosophy of achievement of science objectives with some provision for functional redundancy. This payload is also indicated in Figure 4. Functional redundancy for instrumentation is defined as the ability to achieve the science objectives with two or more different types of measurements. The nominal dayside payload contains five instruments that have not been incorporated into the JPL baseline payload. First, an R. F. click detector was added to provide a coincidence check for the lightning detector to improve the certainty that the recorded flash was of electromagnetic origin. Second, five IR radiometers were added to provide data

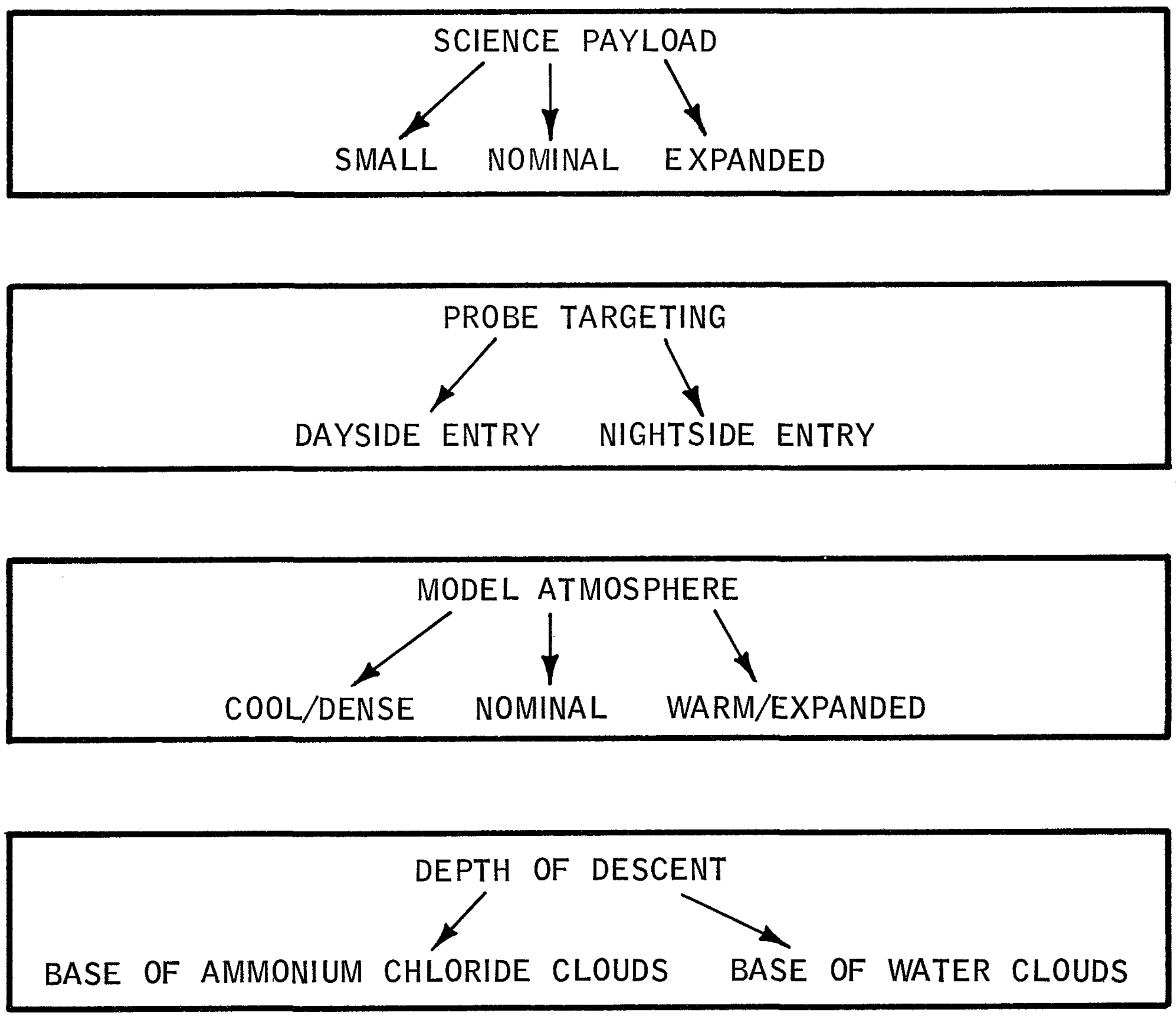

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Figure 3 KEY SCIENCE TRADEOFFS

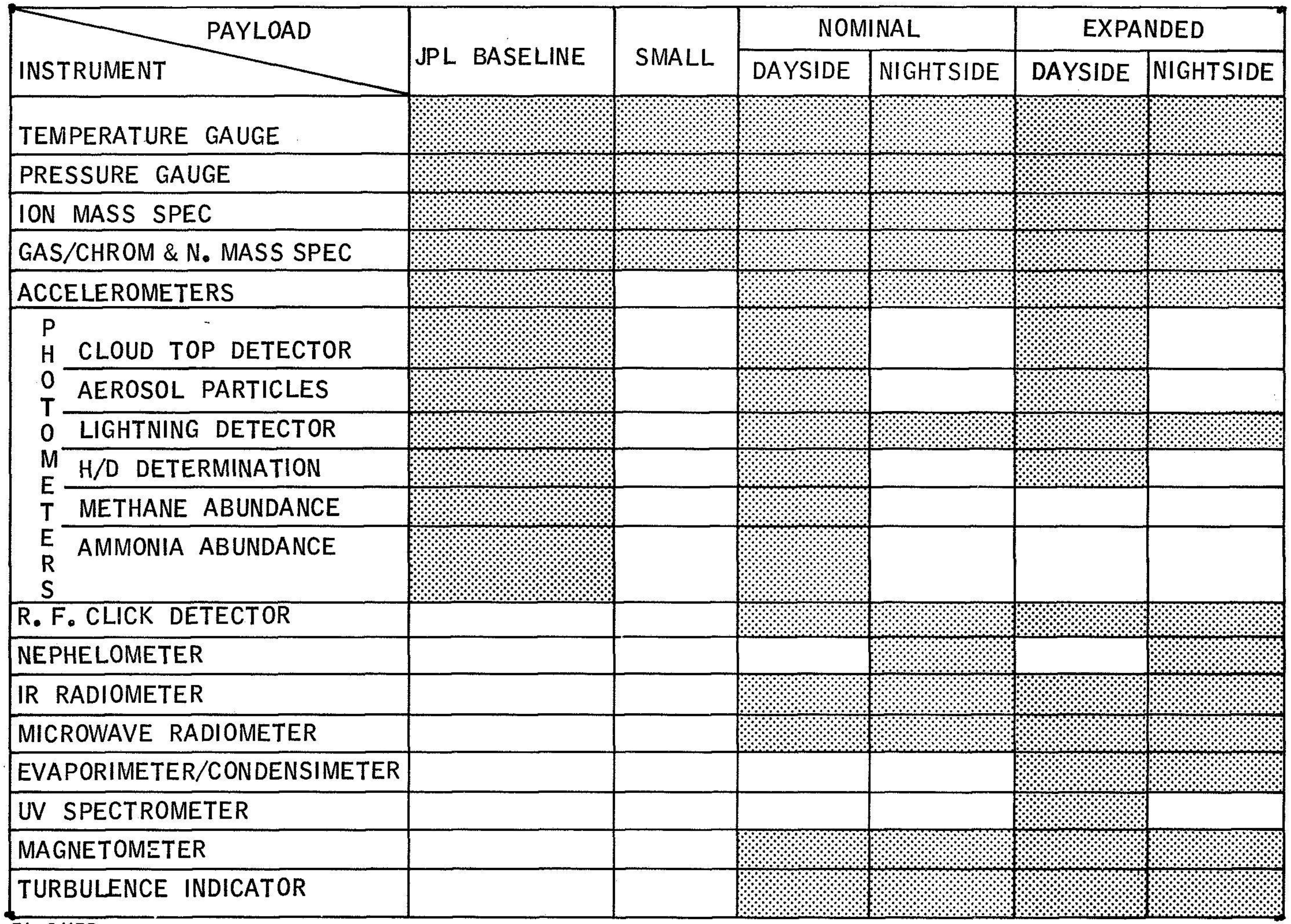

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Figure 4 SCIENCE PAYLOADS

on the IR brightness temperature, and opacity of the clouds in both horizontal and vertical directions. Third, two microwave radiometers were included for measurement of the microwave brightness temperature at great depths and for measurement of microwave opacity. These radiometers are key instruments for this remote sensing mission. A magnetometer and turbulence indicator were added to provide some meteorology and engineering design data. The magnetometer measures the local field and the output can be used to determine whether the atmosphere is coupled with the field. The turbulence indicator is an accelerometer, mounted on the longitudinal axis of the probe, and senses the gustiness of the atmosphere. For the nominal nightside payload, (See Figure 4) all the solar flux sensing, photometer instruments are removed, and a nephelometer is added. Whereas the photometer uses the solar flux as the energy source for its detector, the nephelometer instrument must provide its own light source as well as a detector. The solar photometer instruments are functionally redundant to the gas chromatograph and neutral particle mass spectrometer instruments and an independent measurement of atmospheric composition is lost if they are removed.

An expanded payload was based on the philosophy that instruments would be added to increase the functional redundancy of the measurements that are made by the nominal payload. The expanded dayside payload is indicated in Figure 4. There are two instrumentation differences between the payloads. The photometers that measure methane and ammonia abundance are removed and a UV spectrometer is added. Also an evaporimeter-condensimeter was added to provide more data on cloud structure. For the expanded payload nightside mission, all solar sensing photometry instruments are removed, and a nephelometer is added.

The selection of the instrumentation complement for the small payload is premised on the philosophy of inclusion of a minimum number of instruments that can conduct measurements that are unique to a probe that descends below the cloud tops. The small science payload is shown in Figure 4. Since no solar sensing instrument is included, there is no distinction between dayside and nightside operation. An ion mass spectrometer is added to allow the possibility of return of data from the upper thresholds of the atmosphere. In the event the probe does not survive entry, return of information on the composition of the upper atmosphere is of cosmological importance. This data, albeit limited, provides an important failure mode return. Note that in this small payload, the thermal structure of the atmosphere can only be determined to the cloud base. A candidate additional instrument is the microwave radiometer which can provide data on temperature gradients below the clouds. Use of the phenomenon of chemical stratification is available to the reduction of data of all payloads. This phenomenon is particularly useful for the small payload due to the absence of solar photometers to help resolve chemical and isotopic composition ambiguities. Chemical stratification, or a separation of some atmospheric constituents with altitude is caused by differing thermophysical (PVT) relationships of the constituents.

In Table 1, there is presented a description of the entry probe instrumentation that is previously cataloged according to payload in Figure 4. There are some changes with respect to the JPL baseline payload. The aerosol photometer and cloud top detector photometer of the JPL baseline payload have been combined into a single instrument called the aerosol photometer. The methane abundance photometer and the ammonia abundance photometer that operate in the near infrared region in the JPL payload have been removed and a ultra violet photometer

TABLE 1

INSTRUMENTATION DESCRIPTION

INSTRUMENT	WEIGHT, LB	POWER, W	VOLUME, INCHES	SAMPLING RATE	BIT/SAMPLE	DESCRIPTION
TEMPERATURE GAUGE	1.0	0.2	15.0	1/KM	9	Two units; deployed at 0.7M; data returned from one unit
ACCELEROMETER	1.0	1.0	6.0	10/SEC	7	Four units; triad at C.G.; plus one redundant on-axis; store data during blackout from all units
PRESSURE GAUGE	2.0	0.1	10.0	1/KM	7	Two units; ported at 0.7M; data returned from one unit
U. V. PHOTOMETER	1.3	0.8	24.0	$1/0.1\triangle P$*	40	One unit; five 200Å channels, centered on 400, 700, 1200, 1900 and 2500Å
GAS CHROMATOGRAPH/ NEUTRAL PARTICLE MASS SPEC.	7.0	12.0	320.0	3/CLOUD LAYER	287/SCAN	One unit; sample above, within and below each cloud layer; for a G.C. package/N.P.M.S. the total bits/ scan is 522.
U. V. SPECTROMETER	12.0	4.0	400.0	$1/0.1\triangle P$	160	One unit; 16 spectral of 100Å average width from 1300 to 2800Å
H:D PHOTOMETER	0.35	0.2	6.0	$1/0.1\triangle P$	10	One unit; single channel at 4.55μ
AEROSOL PHOTOMETER	0.65	0.4	12.0	$1/0.1\triangle P$	20	Two channels near 1μ
NEPHELOMETER	4.0	3.0	100.0	$1/0.1\triangle P$	10	One unit; one port for light source; one port for detection
EVAPORIMETER-CONDENSIMETER	2.0	10.0	70.0	$1/0.1\triangle P$	9	One unit; one port for light source; one port for detection
OPTICAL FLASH DETECTOR	2.0	1.0	100.0	1/KM	16	One unit; record number of clicks and coincidence with optical flash detector
R. F. CLICK DETECTOR	2.0	1.0	100.0	1/KM	16	One unit; record number of clicks and coincidence with optical flash detector
IR RADIOMETER	1.0	1.5	25.0	3/CLOUD LAYER	10	Five units; forty-five deg. spacing between zenith and nadir; sensitive at $\lambda > 4\mu$
MICROWAVE RADIOMETER	2.5	1.0	200.0	3/CLOUD LAYER	10	Two units; one looking at zenith and the other at the nadir, $\lambda > 3$ cm
MAGNETOMETER	3.2	0.3	50.0	1/KM	16	One unit; endoatmospheric sampling
MAGNETOMETER	3.2	0.3	50.0	1/DAY	16	One unit; exoatmospheric sampling
ION MASS SPEC.	3.0	1.0	80.0	2/SEC	180/SCAN	One unit; data collected and stored for one minute prior to entry (endoatmospheric)
TURBULENCE INDICATOR	2.0	2.0	10.0	1/KM	18	One unit; senses frequency and magnitude of gustiness with low range on-axis accelerometer

*ONE SAMPLE PER EACH 10% INCREASE IN PRESSURE (CLOUD TOP PRESSURE IS INITIAL CONDITION) operating at 400, 700, 1200, 1900, and 2500Å has been substituted. The advantage of the ultraviolet photometer over the infra-red photometer is that the requirement for direct view of sunlight is removed. Two instruments that are key to this mission which terminates at the cloud base are the infra-red and microwave radiometers which have been added to provide data that will permit the determination of thermal structure.

One of the crucial problems in understanding the thermal structure of the atmosphere of Jupiter is determination of the opacity as a function of both wavelength (in the microwave and infra-red) and attitude. Because of the important contribution to the thermal opacity due to the cloud layers, an infra-red radiometer aboard an entry probe could be used to locate and measure the temperatures of the cloud layers either above or below the entry probe. Further, should there be an extensive "clear" region below the clouds, the infra-red radiometer would permit the approximate measurement of the temperature at great atmospheric depths. The microwave radiometer would always allow measurement to great depths whether or not the base of the cloud layer is reached, and a clear region is found, since the scattering of energy at microwave frequency from the clouds is small due to its large wavelength in comparison to the anticipated dimensions of cloud particles. At infra-red frequencies, the wavelength is comparable to the cloud particle dimensions. Once the remote brightness temperature is determined, it is possible to calculate an atmosphere lapse rate assuming that simultaneous temperature, pressure, and composition is also available.

In Table 2 there is presented a list of instruments that correspond to the list in Table 1, and the usefulness of the instrument in achieving the science objectives is indicated. This qualitative evaluation shows both direct and

TABLE 2

INSTRUMENT SELECTION FOR ACHIEVEMENT OF SCIENCE OBJECTIVES

SCIENCE OBJECTIVE / INSTRUMENT	ABUNDANCE	STRUCTURE	CLOUDS	ORGANIC MATTER	COLORING MATTER
TEMPERATURE GAUGES	-	D	D	-	-
ACCELEROMETERS	-	D	-	-	-
PRESSURE GAUGES	-	D	I	-	-
UV PHOTOMETER	D	D	I	I	I
UV SPECTROMETER	D	D	I	I	I
NEUTRAL PART. MASS SPEC. AND GAS CHROMATOGRAPH	D	I	D	D	D
H:D PHOTOMETER	D	-	-	-	-
AEROSOL PHOTOMETER	-	I	D	-	-
NEPHELOMETER	-	I	D	-	-
EVAPORIMETER-CONDENSIMETER	-	I	D	-	-
OPTICAL FLASH DETECTOR	-	-	-	D	D
R. F. CLICK DETECTOR	-	-	-	D	D
IR RADIOMETER	-	D	I	-	-
MICROWAVE RADIOMETER	-	D	I	-	-
ION MASS SPEC.	D	-	-	-	-

D - DIRECT MEASUREMENT
I - INDIRECT MEASUREMENT

indirect measurements, and the capability of the instruments in providing information about a particular science objective.

The gross science payload characteristics for five classes of science payload is presented in Table 3. For purposes of comparison, the JPL baseline payload is also indicated. Note that this payload is designed to achieve the science objectives by in situ measurement during descent to 1000 atm. The important differences in the nominal dayside payload and JPL baseline payload are the total bits transmitted and the payload weight. The major bit contributors in the JPL payload are the outputs from the temperature and pressure gauges which are sampled once every 300 meters of descent. In the nominal model atmosphere the altitude difference from achievement of 0.7 Mach No. to 1000 atm is 647 Km. Whereas the temperature and pressure are sensed once per kilometer in the nominal dayside science payload, and the altitude difference is 169 Kilometers from 0.7 Mach No. to the base of the clouds. (17 atm) The larger weight of the nominal dayside science payload in comparison to the JPL baseline payload results from inclusion of five infra-red radiometers, two microwave radiometers, and R.F. click detector, two magnetometers, and a turbulence indicator to measure gustiness.

3.2 PROBE TARGETING

A first choice target for a Jupiter entry probe is a "typical" dark or light band. Latitudes near the equator and near the poles are excluded. Near the equator,the Coriolis forces that dominate the dynamics of the atmosphere vanish, and so the near equatorial zone is not typical. The higher and polar latitudes are not typical. At the higher latitudes, the insolation is reduced and the thermal structure of the atmosphere, as evinced by the presence of "polar caps", could be expected to be significantly different. The total surface area at these high latitudes is considerably less than the area at the lower latitudes and so not representative. Near the poles, the intense depole field may conceivably be

TABLE 3

SCIENCE PAYLOAD CHARACTERISTICS

PAYLOAD / CHARACTERISTIC	JPL BASELINE	SMALL	NOMINAL		EXPANDED	
			DAYSIDE	NIGHTSIDE	DAYSIDE	NIGHTSIDE
WEIGHT, LB	19	16	43	45	56	47
POWER, W	18	15	34	36	48	46
VOLUME, IN^3	485	450	1321	1379	1767	1449
TOTAL BITS	45,000*	5200	27,700	25,900	43,000	38,600

* TO 1000 BARS

dynamically coupled with the lower atmosphere. Atmospheric descent between longitudes of ± 70 deg of the sub-solar point is desirable to permit utilization of the photometers that use the sun as energy source. These photometers are of value due to their functional redundancy. The reason that the allowable longitude zone is cut-off 20 deg on the sunlit side of the terminator is to allow for the reduction of the influence of cloud top irregularities on the photometer measurements. For example, for entry probe vertical descent at the terminator the sun angle is ninety deg and the electromagnetic path length through the atmosphere is maximum.

In Figure 5, the available dayside targeting areas are shown. The boundaries are approximate. Note that the Great Red Spot is excluded as a target because it is very atypical. For darkside targeting, the longitude constraints are removed. It appears that darkside targeting is compatible with achievement of science objectives. However, dayside targeting is preferred so that the sun sensing photometers and their functionally redundant atmospheric composition measurements are available. Also data gathered on the dayside by an entry probe can be used to corroborate Earth based dayside observations.

3.3 MODEL ATMOSPHERE

Three model atmospheres were provided as a guideline for the mission study, and are termed the nominal model atmosphere, the cool/dense model atmosphere, and the warm/expanded model atmosphere. The temperature and pressure profiles and atmospheric constituents of these model atmospheres were used to construct cloud models. These models are shown in Figure 6. It is important to note that the base of the cloud layer occurs at a pressure of 17 atm in the nominal model atmosphere. Therefore, the entry probe must survive to a relatively benign pressure and temperature of 17 atm at 425 deg K in comparison with descent to 1000 atm and a corresponding temperature of 1425 deg K. In the cool/dense model atmosphere the base of the clouds occurs at a pressure of 525 atm and a

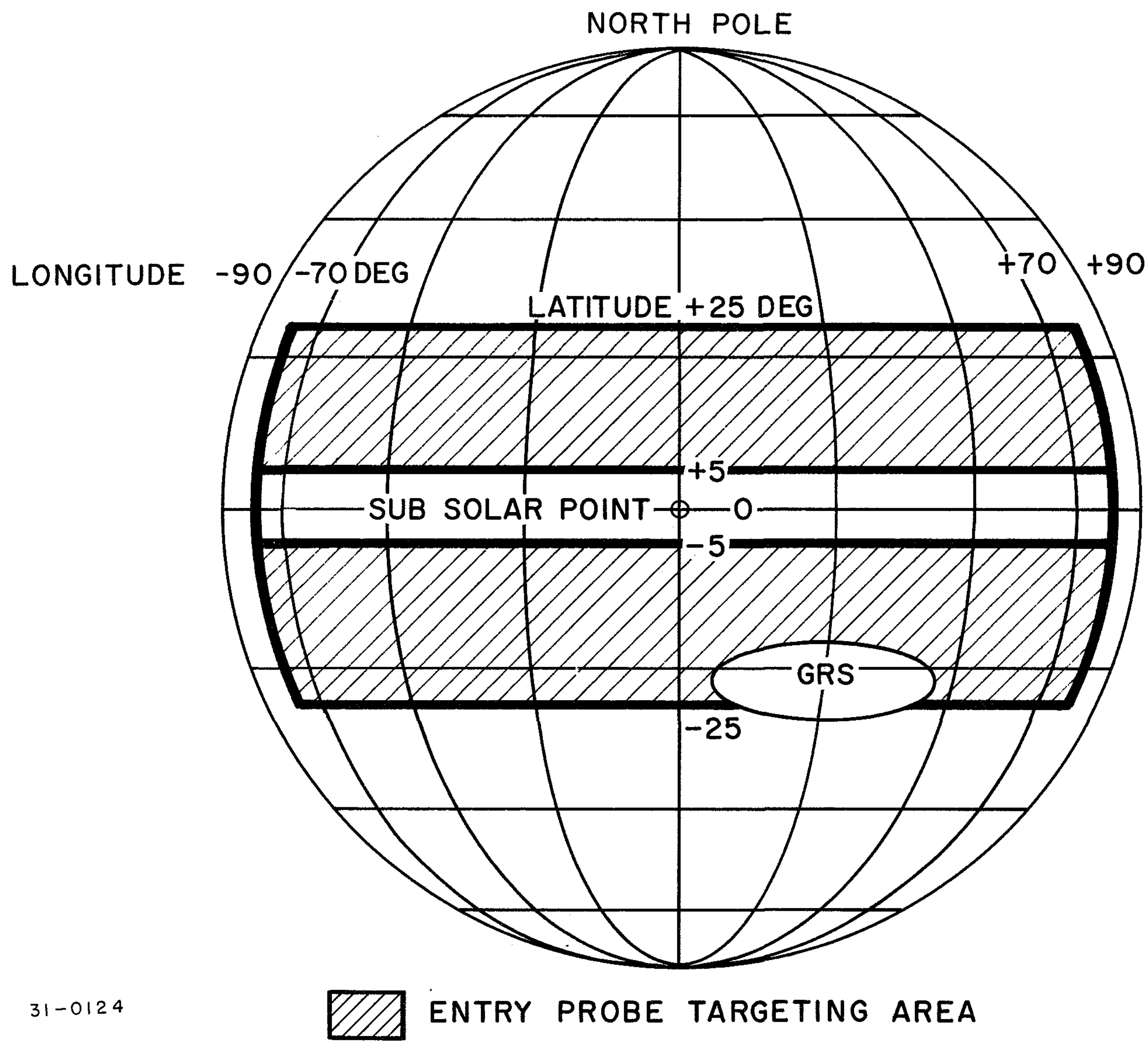

Figure 5 DAYSIDE PROBE TARGETING AREAS

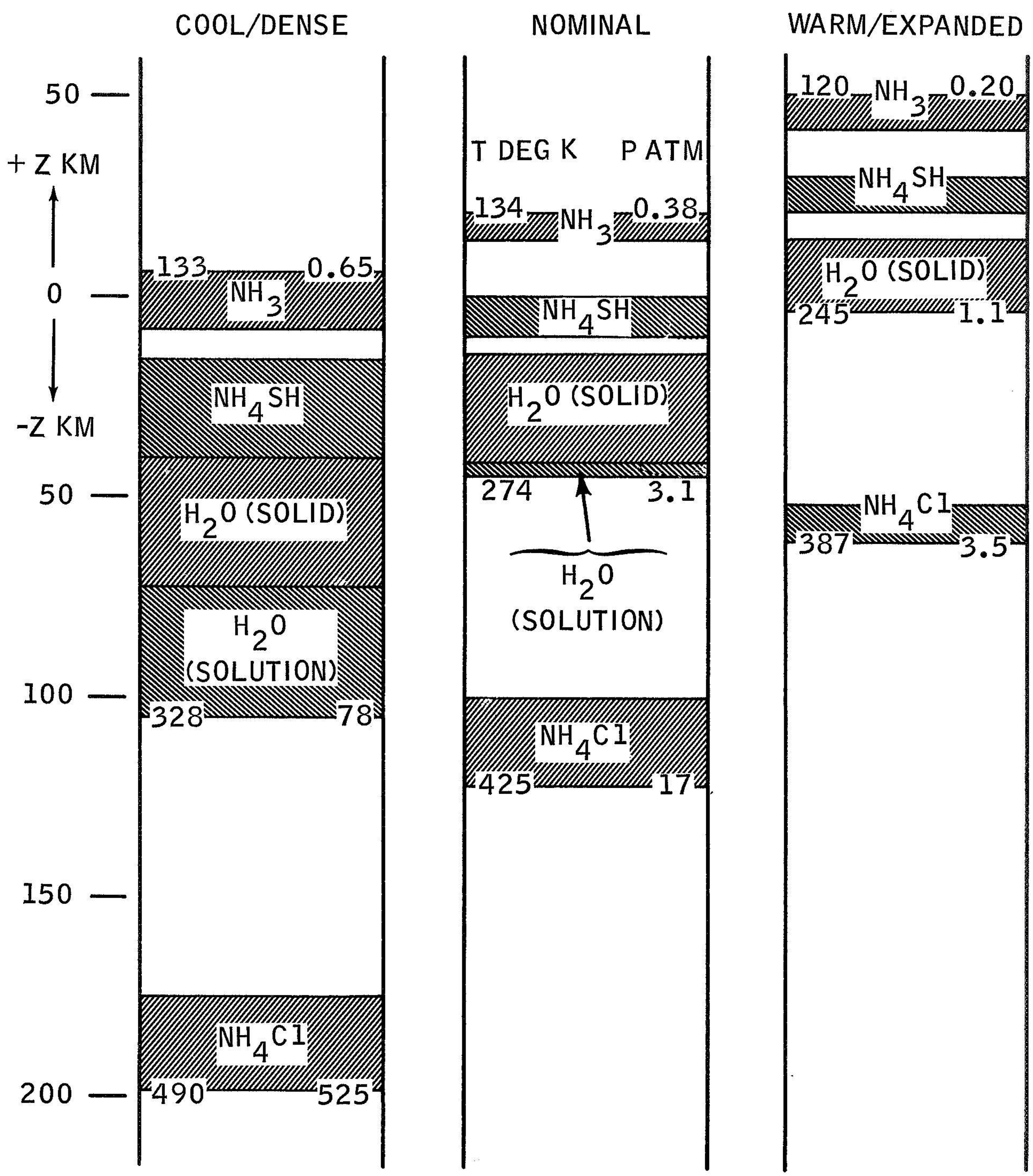

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Figure 6 JUPITER CLOUD MODELS

pressure of 490 deg K in comparison to descent to 1000 atm and a temperature of 572 deg K. In the warm/expanded model atmosphere, the base of the clouds occur at a pressure of 3.5 atm and a temperature of 387 deg K whereas the temperature at the 1000 atm level is 3771 deg K. In the atmosphere with the higher temperature gradient, the condensation temperatures of different gases are reached within a narrower altitude interval; therefore, the cloud layers lie closer together. Of the three model atmospheres considered, the troposphere lapse rate is greatest in the warm/expanded model and least in the cool/dense model.

The influence of the model atmosphere on entry probe with nominal dayside payload is shown in Table 4. Maximum G loads are based on a shallow entry angle condition of -15 deg. It can be seen that the G loads are greatest for entry into the cool/dense model atmosphere. This is a direct result of the small scale height associated with the lower stratosphere temperature. A small scale height results in entry probe deceleration over a shorter path length with the attendent larger deceleration loads. As the model atmosphere varies from warm/expanded to nominal to cool/dense, the entry probe weight increases as a result of increasing aeroshell structural weight, auxiliary structural weight, and pressure vessel weight. In the cool/dense model atmosphere, the relay link must operate at UHF to reduce R.F. transmission losses. Note that a direct communication link is not possible for entry into the cool/dense model atmosphere since DSN operates at S-band. It was determined that at S-band, the R.F. losses associated with vertical propagation through the cool/dense model atmosphere is 55 dB, for the nominal model atmosphere 3 dB, and for the warm/expanded model atmosphere 0.1 dB.

TABLE 4

INFLUENCE OF ATMOSPHERIC MODEL ON ENTRY PROBE DESIGN

ATMOSPHERE / CHARACTERISTICS	COOL/DENSE	NOMINAL	WARM/ EXPANDED
MAXIMUM G	1250	525	260
ENTRY PROBE WT. AT SEPARATION, LB	630	352	316
RELAY LINK FREQUENCY	UHF	S	S
TRANSMITTER OUTPUT POWER, W	32	25	16
TOTAL BITS	34,000	27,000	24,000

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The influence of the model atmosphere on the entry probe weight is shown in Figure 7 for both the nominal payload and small payload. It can be seen that the weight penalty for entry and descent to the base of the ammonium chloride clouds for an entry probe carrying the nominal payload in excess of one hundred pounds. It is of interest to note that a probe designed for entry into the cool/dense model atmosphere with the small payload is roughly equivalent in weight to a probe designed for entry into the nominal atmosphere with the nominal payload.

It was determined that the warm/expanded model atmosphere does not provide any significant entry probe design constraint and that the cool/dense model atmosphere sets the design requirements for most entry probe systems and subsystems.

3.4 DEPTH OF DESCENT

The influence of depth of atmospheric descent on entry probe design was evaluated, and limited to consideration of only the cool/dense model atmosphere. A comparison was made between descent to the base of the water clouds and descent to the base of the cloud layers, the ammonium chloride clouds. The water clouds were chosen because about ninety-eight percent of the total cloud mass lies above the base of these clouds, and descent to their base would allow for achievement of most of the science objectives. Descent to the base of the clouds, the ammonium chloride clouds, would permit an unobstructed view of the lower atmosphere by the radiometers. It would be valuable if the brightness temperature of the lower atmosphere can be measured without the necessity of having to account for the influence of attenuation by this lowest layer.

A reduction in the depth of atmospheric descent does not influence the G loads experienced by the probe, and influences the aeroshell structure and heatshield in a secondary manner. Since the pressure and temperature is lower if the depth of descent is reduced, then the pressure vessel weight and insulation

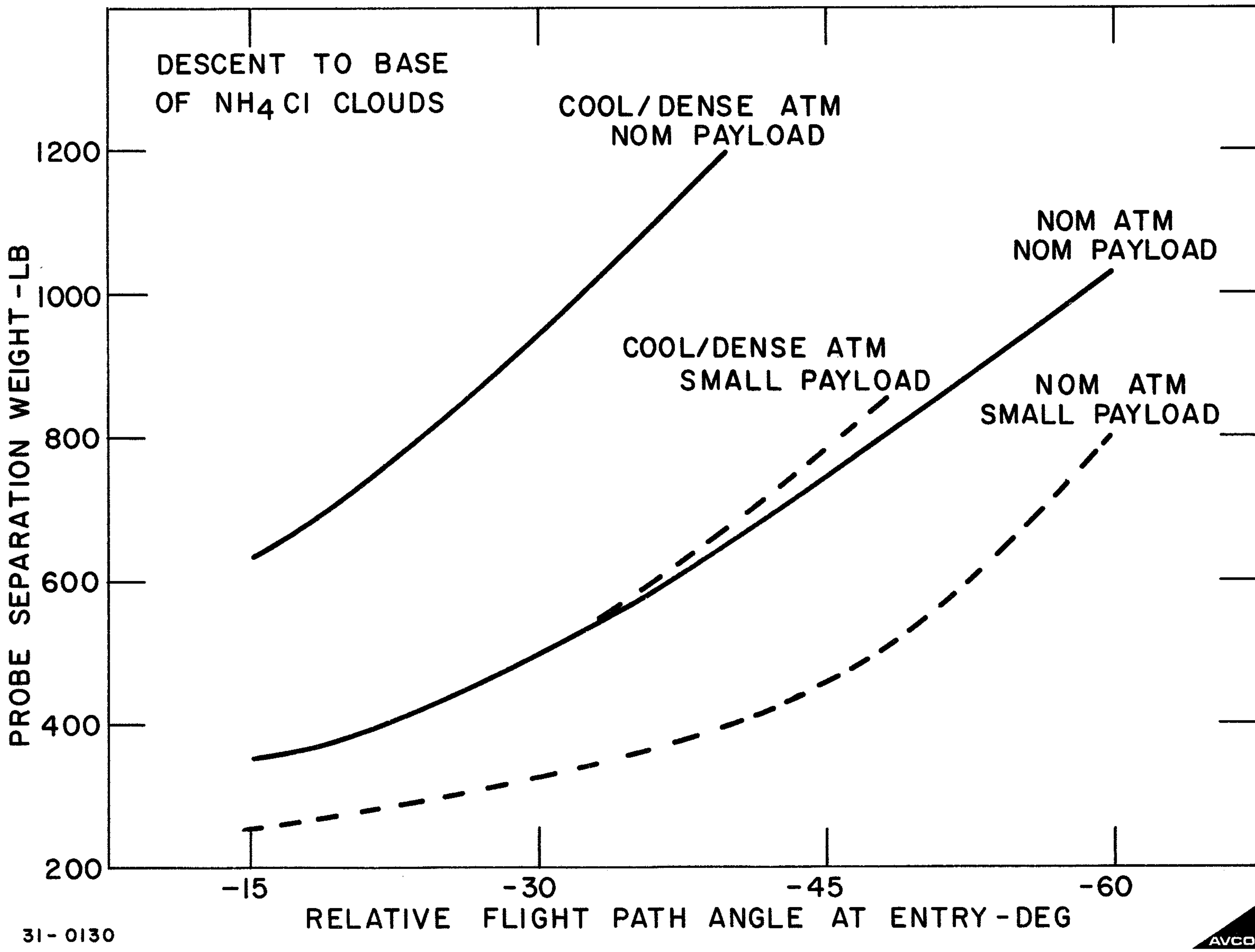

Figure 7 INFLUENCE OF ATMOSPHERE ON PROBE SEPARATION WEIGHT

weight requirements are also diminished. For the same aeroshell diameter, the entry probe ballistic parameter is reduced, and so are the aeroshell loads and subsequent aeroshell structural weight. The influence of depth of descent on entry probe separated weight is shown in Figure 8. It can be seen that the reduction in weight varies from about 50 lb for shallow angle entry to about 100 lb for steep angle entry. A comparison with Figure 7 shows that the probe weight for descent to the base of the water clouds in the cool/dense model atmosphere is significantly greater than probe weight for descent to the base of the ammonium chloride clouds in the nominal atmosphere.

The R. F. attenuation loss for descent to the base of the water clouds and ammonium chloride clouds for the three model atmospheres is shown in Table 5.

TABLE 5

R. F. LOSS FOR VERTICAL TRANSMISSION AT S-BAND

MODEL / ATM LEVEL	COOL/DENSE	NOMINAL	WARM/EXPANDED
BASE OF WATER CLOUDS	20 dB	0.2	0
BASE OF AMMONIUM CHLORIDE CLOUDS	55 dB	3	0.1

The increase in R. F. loss in the cool/dense model atmosphere is caused by the higher pressure at which the clouds are located which results in more ammonia, the principal absorber, along the communication line of sight. Note that the R. F. loss in the cool/dense model atmosphere is reduced from a non feasible 55 dB to a very large loss of 20 dB. For descent into the cool/dense model atmosphere, a lower radio frequency must be considered.

If the cool/dense model atmosphere is realistic, then descent to the base of the water clouds can offer a substantial reduction in design problems. If the

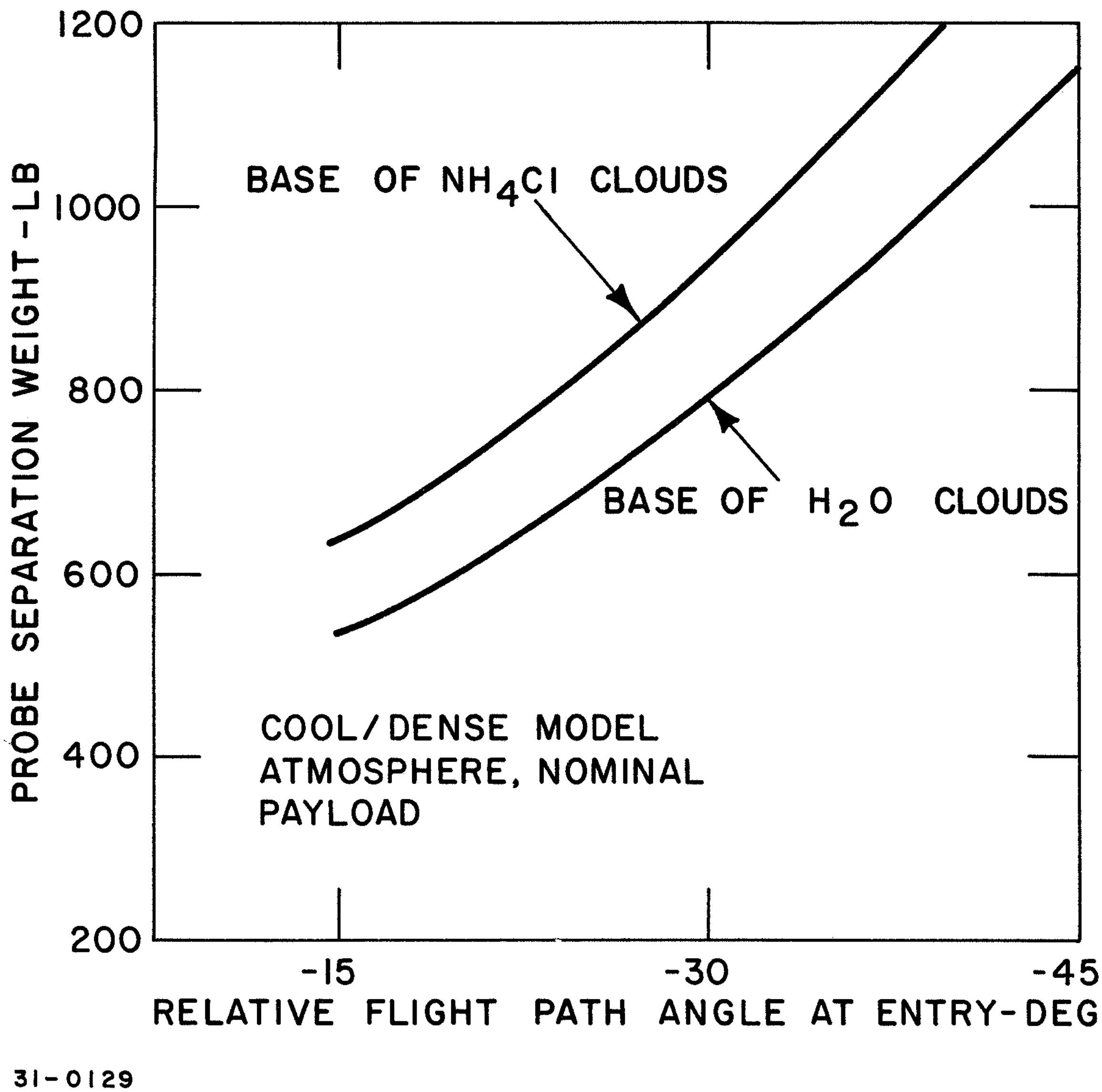

Figure 8 INFLUENCE OF DEPTH OF DESCENT ON PROBE SEPARATION WEIGHT

nominal atmosphere is realistic, then descent to the base of the cloud layers, the ammonium chloride cloud will not result in undue engineering design penalties.

4.0 ENGINEERING TRADEOFFS

Four key tradeoffs were recognized for evaluation of the science return, and are shown in Figure 9. These tradeoffs include 1) the influence of the year of launch, 2) the type of interplanetary trajectory either fast or slow, 3) the selection of entry angle, 4) the performance evaluation of a direct or relay communication link, and 5) the influence of selection of TOPS or Pioneer F/G spacecraft as an entry probe bus.

4.1 LAUNCH OPPORTUNITY

Launch opportunities in 1978, 1979, and 1980 were investigated and compared. It was determined that the injection energy requirements are reduced for the later opportunities. This reduction is due to the closer proximity of Jupiter to the line of nodes in the later opportunities. The line of nodes is the intersection between the Earth's orbital plane and the Jovian orbital plane. As Jupiter encounter approaches the line of nodes, the component of the velocity nominal to the Earth's orbital plane is reduced.

Both fast-Type I and slow-Type II interplanetray trajectories were considered in this study. A spacecraft launched along a Type I trajectory encounters Jupiter prior to apoapsis on the Earth to Jupiter transfer ellipse, whereas a spacecraft launched along a Type II trajectory encounters Jupiter after apoapsis passage along the transfer ellipse. Typical Type I and Type II trajectory configurations are shown in Figure 10. The difference in flight time between the trajectories is about 2 years with 650 days associated with Type I and 1450 days associated with Type II. Aside from the reliability question associated with the longer flight time Type II transfers, more time (186 days for Type I vs. 202 days for Type II) is spent in the meteorite belt and hence more meteorite protection material is needed to ensure system operation at encounter.

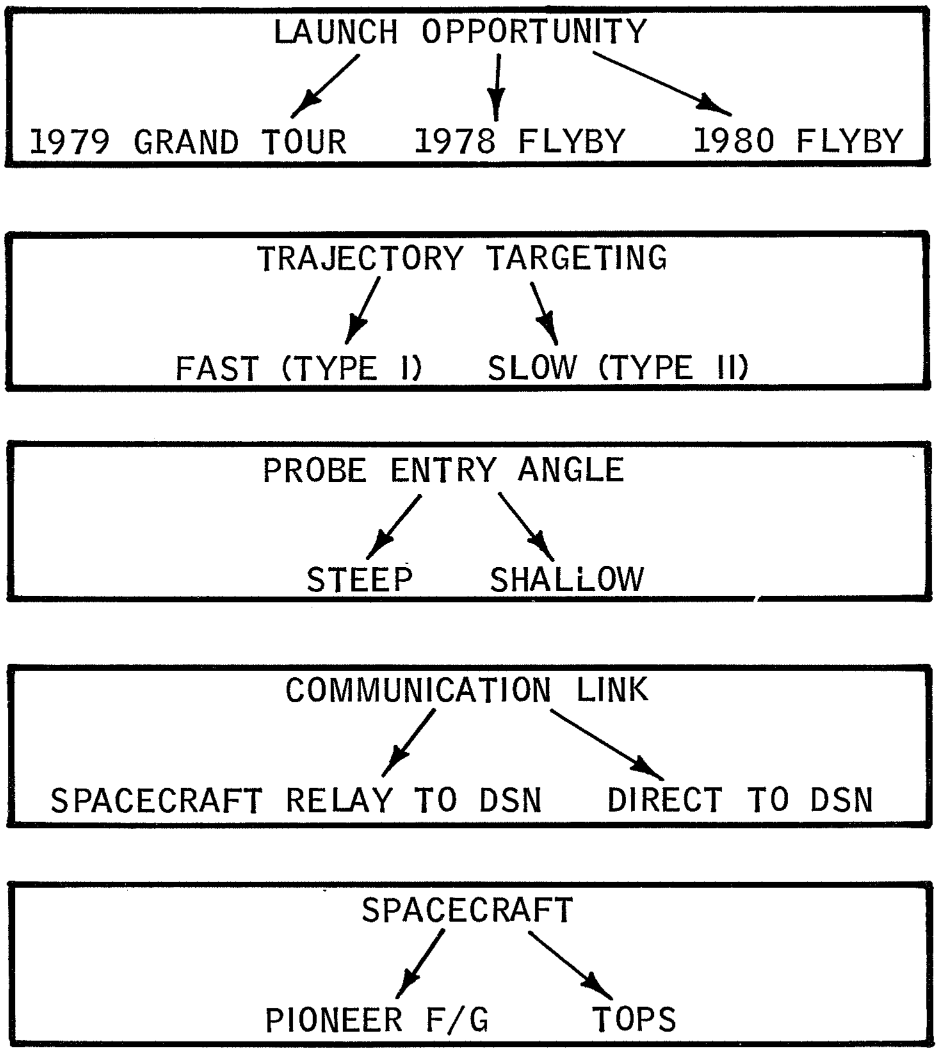

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Figure 9 KEY ENGINEERING TRADEOFFS

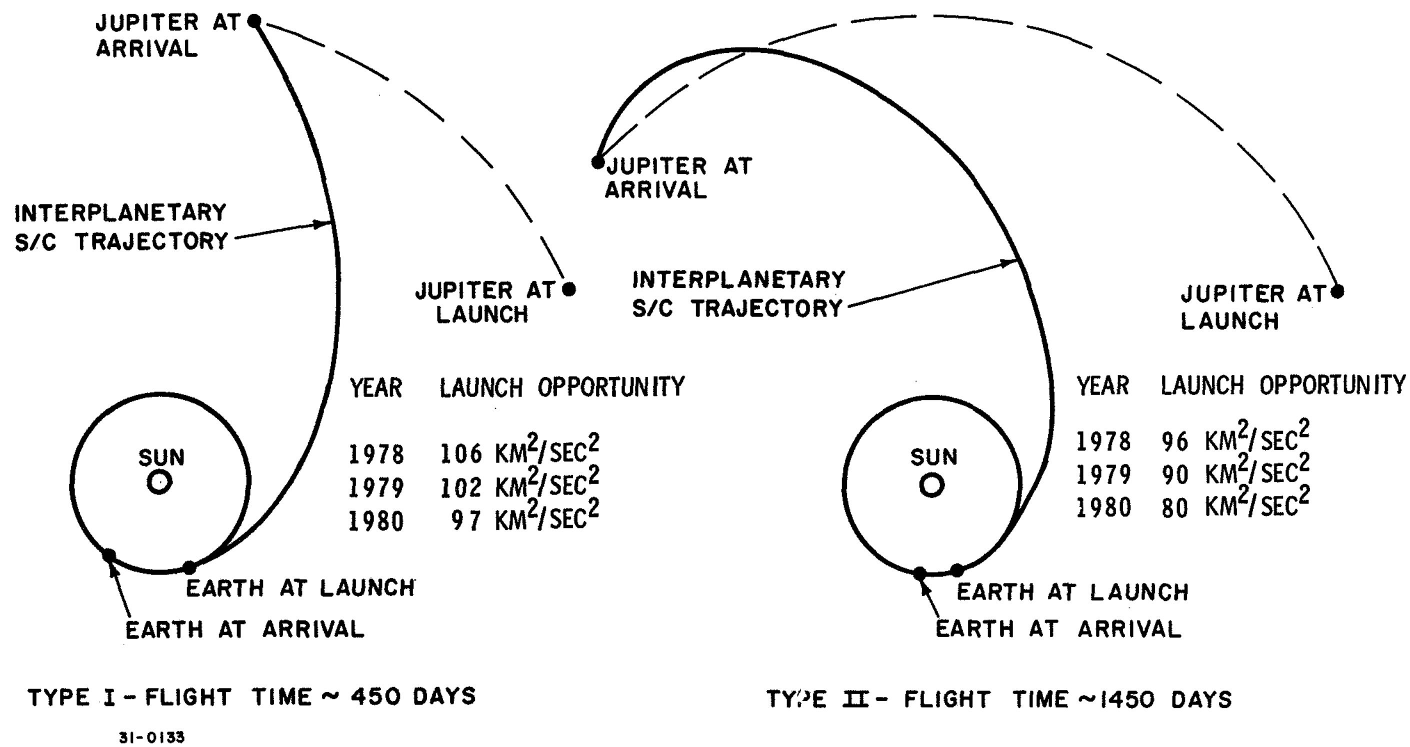


Figure 10 INTERPLANETARY TRAJECTORY CONFIGURATIONS

The injection energies associated with both Type I and Type II transfer trajectories during the 1978, 1979 and 1980 launch opportunities is shown in Table 6. These results indicate that slightly lower injection energies are associated with the Type II transfer trajectories and when operating in the vicinity of minimum injection energies the later launch opportunities exhibit some improvement in the magnitude of the injection energy.

TABLE 6

COMPARISON OF INJECTION ENERGY

LAUNCH OPPORTUNITY	INJECTION ENERGY, KM^2/SEC^2	
	TYPE I*	TYPE II**
1978	106	96
1979	102	90
1980	97	80

*140 DEG ~ APPROACH VELOCITY ANGLE AND 650 DAY FLIGHT TIME

**60 DEG ~ APPROACH VELOCITY ANGLE AND 1400 DAY FLIGHT TIME

For a 2000 lb flight vehicle weight, a Titan III D/5 Segment Solid Rocket Motors/Stretched Centaur/Burner II launch vehicle is required in 1978, and the smaller Titan III D/5 Segment Solid Rocket Motors/Centaur/Burner II can be used in 1980.

Furthermore, it is found that certain key trajectory parameters were essentially independent of launch opportunity or transfer trajectory type and basically only depended on the encounter date. These parameters are direction of the approach asymptote relative to the sun line, magnitude of the hyperbolic approach velocity, flight time, and encounter communication range.

Since the direction of the approach asymptote is the key parameter that governs the entry angle for entry at a specified location the other parameters like flight time, communication range and magnitude of the hyperbolic approach velocity are automatically fixed. Consideration of and tradeoffs between all these parameters is essential in the selection of the approach asymptote angle. Flight time must be considered from a reliability point of view. Specific approach asymptote angles must be considered for direct link telecommunication systems in that it is important to operate in the vicinity of minimum communication range with favorable Earth angles. Since the Earth-Jupiter geometry repeats approximately every thirteen months there are several specific values of approach asymptote angle which yield near minimum communication ranges.

4.2 TRAJECTORY TARGETING

For outer planet missions, Type I trajectories typically approach the planet from the dayside leading edge whereas the Type II trajectories typically approach from the nightside leading edge. In Figure 11 there is shown the encounter geometry for three typical missions: a Type II dayside relay link, a Type I night relay link and a Type II dayside direct link. During the 1978, 1979 and 1980 launch opportunities minimum energy Type II trajectories approach Jupiter about 30 degrees behind the morning terminator and permit shallow entry angle dayside missions with entry in the early afternoon and mission termination after 1 hour well in front of the evening terminator. With Type I transfers the approach is within 40 degrees of the Jupiter-Sun line and shallow entry angles force the entry location to be in the vicinity of the evening terminator.

For a direct link mission, entry locations in the vicinity of the sub-solar point are dictated by the fact that the Earth is never more than 12 degrees from the Jovian sub-solar point and hence Type II trajectories must be employed to achieve even reasonably low entry angles.

Typical probe targeting is illustrated in Figure 12 for both Type I dayside and Type II nightside approaches to Jupiter. For the Type I encounters, entry in the vicinity of the evening terminator is required for relative entry angles shallower than about -25 degrees whereas a relative entry angle of about -80 degrees is necessary to enter near the sub-solar point. For a Type II encounter the approach asymptote is behind the morning terminator on the dark side of the planet and entry near the sub-solar point can be achieved with a relative entry angle of -30 degrees. From a science con-

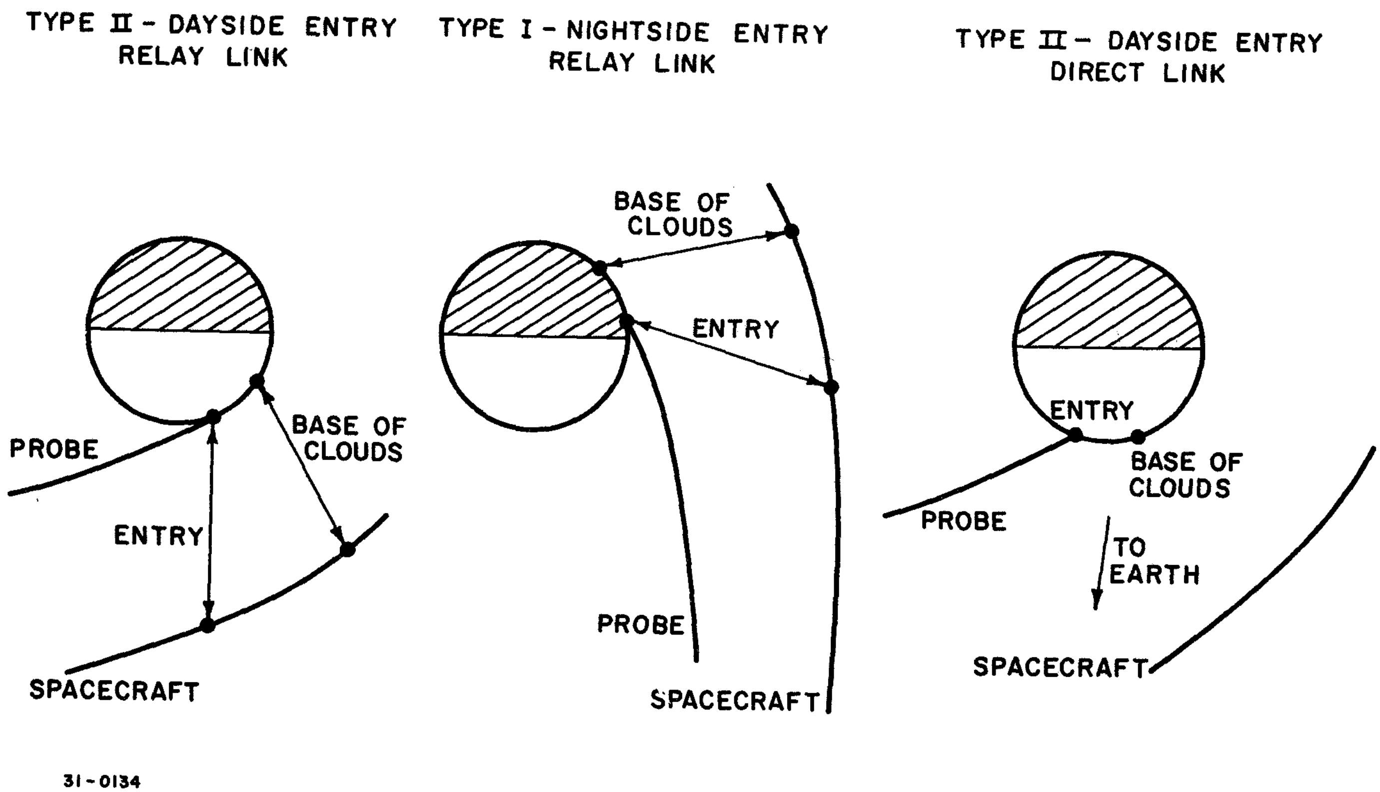
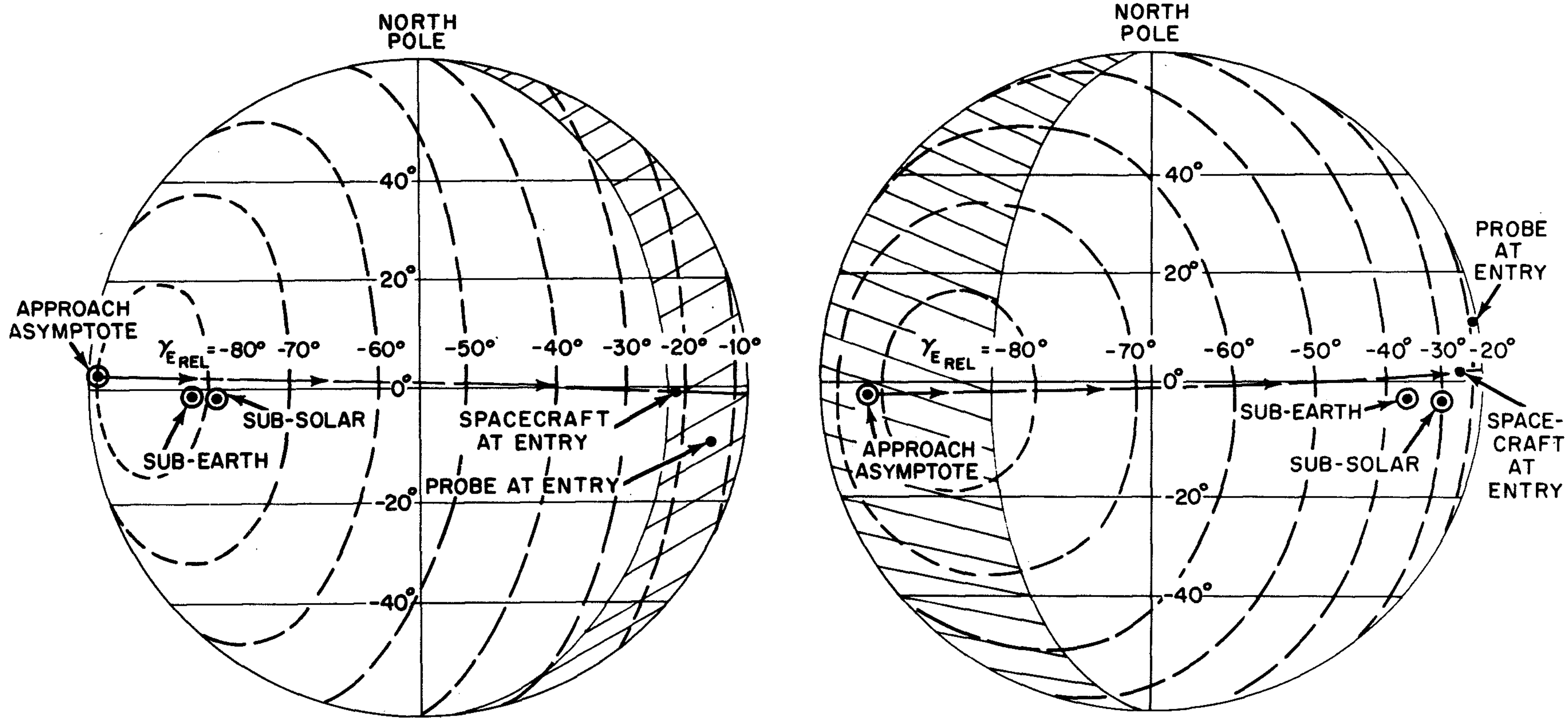


Figure 11 ENCOUNTER TRAJECTORY CONFIGURATIONS



TYPE I

TYPE II

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Figure 12 JUPITER ENTRY ANGLE CONTOURS

sideration it is desirous if the probe is below the base of the clouds while the probe is still 20 degrees in front of the evening terminator to avoid problems associated with cloud top irregularities that give spurious solar extinction values. Therefore, since a 1-hour probe mission is attractive and the planet rotates at a rate of 36 degrees/hour, the probe should enter about 56 degrees in front of the evening terminator for a dayside descent mission, and this mission can only be achieved with shallow entry angles for approach asymptote angles associated with Type II encounters.

The approach trajectory targeting, i.e. dayside or nightside entry; the flight path angle at entry, i.e. steep or shallow; and time of flight, i.e. long or short; are interrelated quantities and only two can be specified. From the viewpoint of science, dayside entry is most desirable. From the viewpoint of minimizing engineering, shallow entry angles and short flight times are desirable. Figure 13 shows this interdependency. It is indicated that both shallow entry angle and Type I trajectories are required to satisfy all goals. However, only long flight time and shallow entry angle, or short flight time and steep entry angle is available. From the viewpoint of engineering development, the shallow entry angle with long flight time is preferred. This avoids high-G and reduces heating in an unknown environment. The development of subsystems with long shelf life can be accomplished with practically no special facilities requirements.

4.3 PROBE ENTRY ANGLE

The flight path angle at entry has a direct influence on the entry probe weight. Entry probe weight increases quite rapidly as the entry angle is increased. In Figure 14 there is shown the variation of entry probe weight with flight path angle. It is assumed that the science payload, and electrical supporting subsystem weights are independent of entry angle. This assumption is based on the following argument. As the G-load increases, the stresses within the element increase. These stresses can be reduced by providing more structural material which will result in an increase in weight, or by miniaturization which tends to reduce the

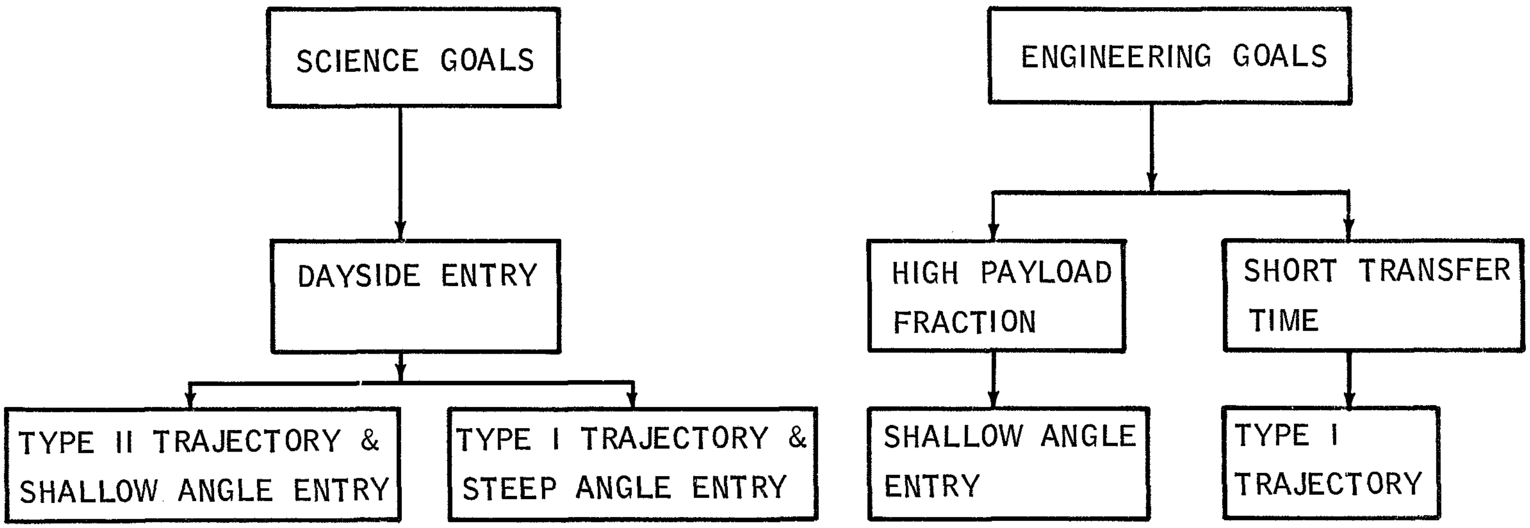

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Figure 13 TRAJECTORY TRADEOFF SUMMARY

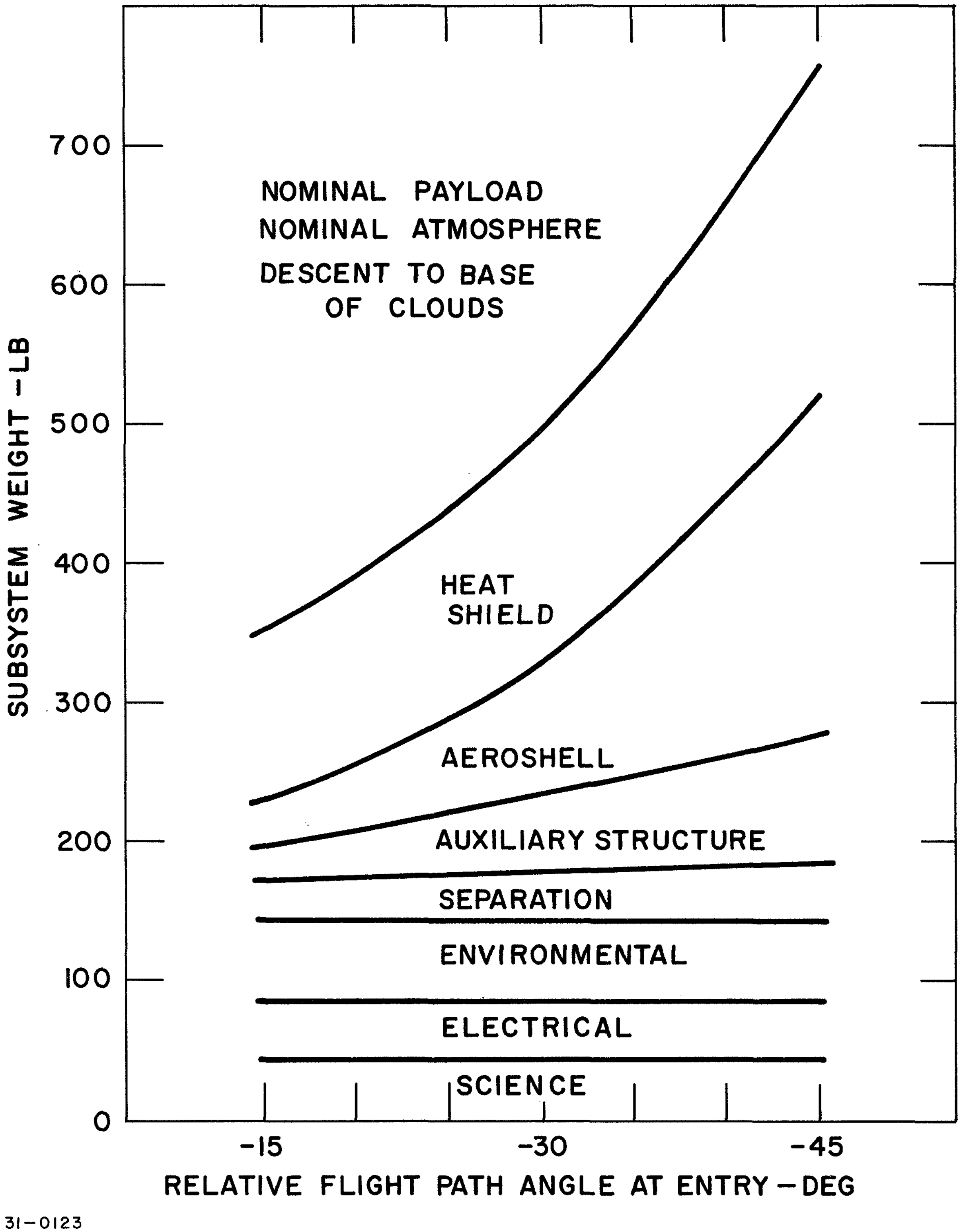

Figure 14 PROBE SEPARATION WEIGHT

mass of material that must be supported. Reduction of the characteristic dimensions of the element in the direction of the deceleration diminishes both weight and stress. The technology continually moves towards greater miniaturization. From Figure 14 it can be seen that the auxiliary structure weight increases slowly but the aeroshell structure weight increases quite rapidly. The data from which Figure 14 was generated is based on a constant entry probe diameter of four feet. Aeroshell structure weight is dependent on both entry angle and ballistic parameter. As the entry angle increases, the aerodynamic pressure loads increase which increase the aeroshell structure weight which increases the ballistic parameter. As the ballistic parameter increases, the aerodynamic loads increase, and so on. Note that the heat shield weight is increasing slowly relative to the aeroshell weight. The heat shield data provided indicates that for a given entry angle the heat shield fraction decreases as entry angle increases. In Figure 14, as the entry angle is increasing, the ballistic parameter is increasing since the aeroshell diameter is held constant. Based on titanium honeycomb construction, it was determined that entry at angles steeper than about -70 deg. are not feasible. Near -70 deg. entry, the available payload starts to approach zero pounds.

Entry probe separation errors cause dispersions in entry angle, and for a relay link, these separation errors also cause dispersions in communication range and communication angle. The skip boundary is about -6 deg. and the dispersion considering error sources consistent with 1975 technology result in about a 7 deg. dispersion, three-sigma. This results in a nominal skip boundary entry angle of - 13 deg. and an entry probe that must be designed to enter at angles that range from -6 to -20 deg. As the entry angle increases, the dispersion in entry angle diminishes. At -30 deg. entry angle, the three-sigma dispersion is reduced to 2 deg. The performance of the relay communication link is dependent on the communication range and angle during entry. It was determined the dispersions in communication range and communication angle were most severe at the steeper entry angles and that higher data rates would be obtained for shallow entry angle targeting. This influence of entry angle on data rate is discussed in Section 4.4.

4.4 COMMUNICATION LINK SELECTION

The communication system requirements are based on the data content of a nominal payload that must gather and transmit data from entry to the bottom of the cloud layers. The accumulation of data bits from a nominal science payload is shown in Figure 15 to be about 27,000 bits. The vertical discontinuities in the data accumulation profile is caused by the output of the gas chromatograph / neutral particle mass spectrometer. This instrument samples once above, within, and below each cloud layer. This total data transfer requirement coupled with the descent time establishes the link data rate, (hence operating threshold) requirements.

A link is deemed satisfactory if the signal strength levels at the worst point in the mission (typically at the base of clouds) exceeds the receiver threshold by an amount at least equal to the linear sum of the adverse tolerances.

Included as part of these tolerances is the antenna gain reduction consistent with a $\pm 15^{\circ}$ angular tolerance for probe attitude disturbance caused by atmospheric turbulence. Also included as a separate tolerance is the probe and spacecraft dispersion effects on link performance.

Fifty watts of transmitter output power is used as the upper bound; this S or L band transmitter performance is consistent with anticipated 1975 technology.

The RF propagation losses from below the Jupiter cloud layers, have been assessed over a range of transmission frequencies from 10^{8} to 10^{10} Hz. The results are shown plotted in Figure 16 for the three model atmospheres. The

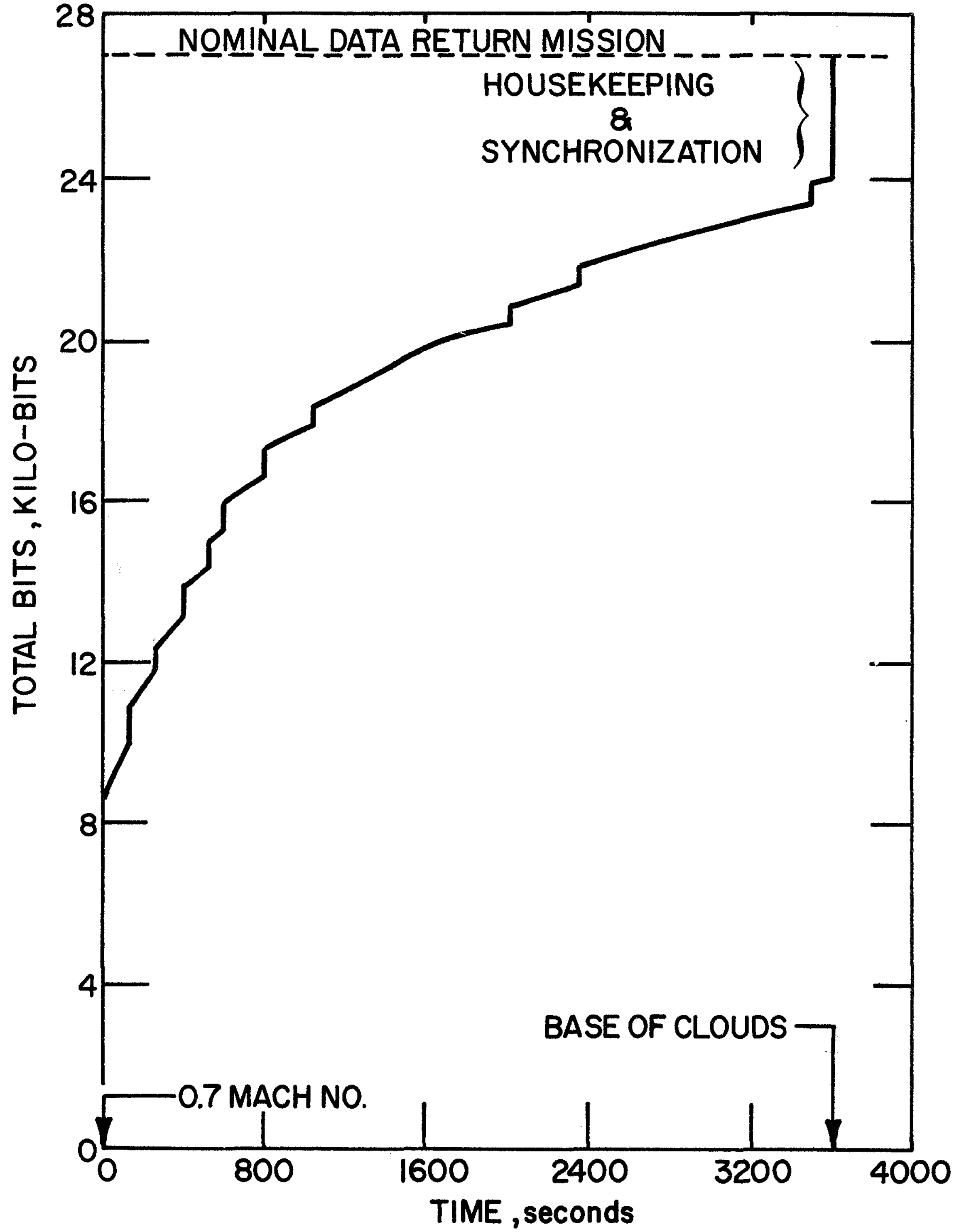

Figure 15 COMMUNICATION SYSTEM DATA TRANSFER REQUIREMENTS

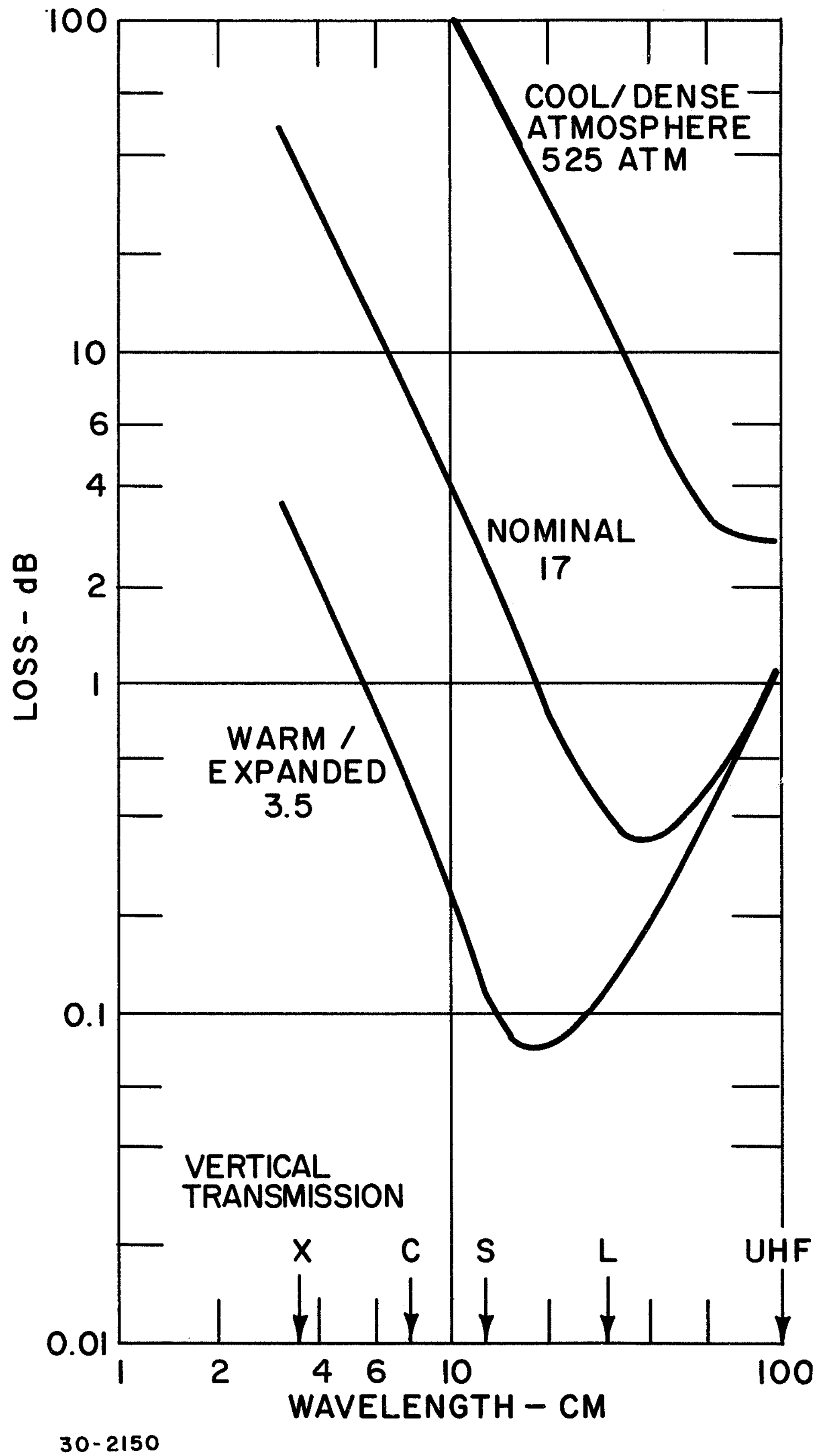

Figure 16 R.F. PROPAGATION LOSSES FROM BOTTOM OF JUPITER CLOUDS

loss composite profile for vertical transmission shown in the figure is based on the sum of the following loss mechanisms: 1) ionospheric attenuation, 2) gaseous (NH_3, H_2O) absorption, 3) refractive losses (all gaseous constituents), and 4) cloud absorption and scattering.

The principle loss mechanism in these profiles at the smaller wavelengths is the gaseous NH_3 absorption which increases with decreasing wavelengths. At the larger wavelengths the ionospheric effects which increase with increasing wavelength is the main component of the loss profile. For the cool/dense atmosphere, it should be noted that the large increases in loss do not result from a larger percentage of NH_3 gas but simply due to the requirement to transmit over longer path lengths.

The sensitivity of the propagation losses to the transmission frequency is significant and plays a major role in the selection of an optimum relay link transmission frequency. For direct link communications, where the link frequency is constrained to S-band, it can be said that no link capability will exist at the base of the clouds in the presence of the cool/dense atmosphere.

Direct Link

There is a unique interplanetary geometry that will provide both minimum range (about 630 million kilometers) and allow for a shallow entry angle in the vicinity of the sub-Earth point. This point was examined for both a 1978 and 1980 launch opportunity. A Type II trajectory with a transfer time of about 1275 days provides the necessary encounter geometry. The variation of data rate with entry angle is shown in Figure 17 for 50w of transmitted power, use of a simple probe antenna, a conical reflector, and the favorable DSN receive only S-band mode. Note that in 1980 a shallower entry angle can be used to achieve a given data rate. In 1978 an entry angle of almost -33 deg and a descent time of 1700 sec combine to provide a total bit output of 27, 000 bits,

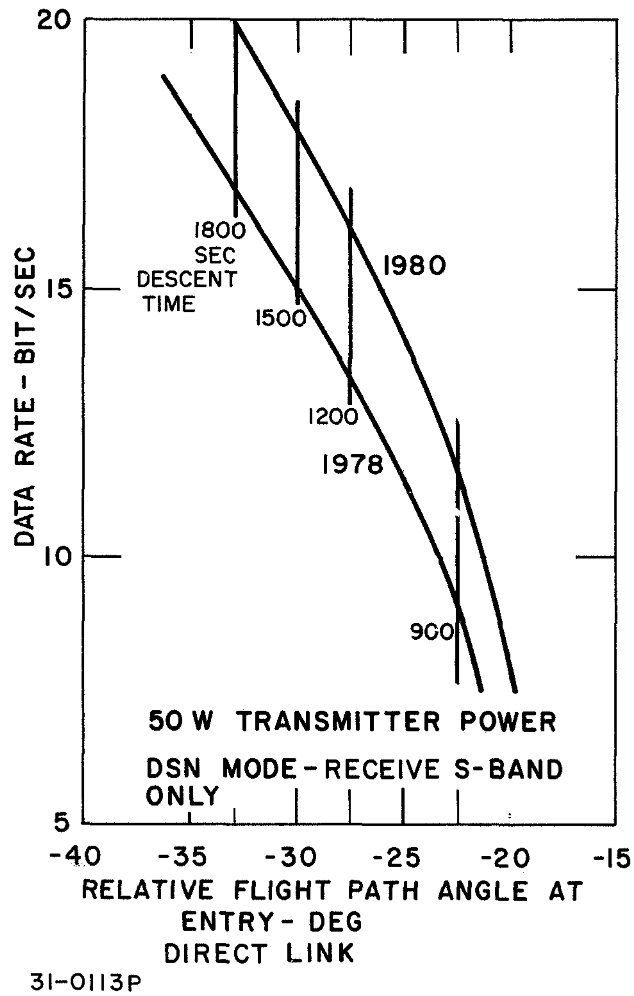

Figure 17 DIRECT LINK COMMUNICATION PERFORMANCE

and in 1980 an entry angle of -29 deg and a descent time of 1600 sec yield 27,000 bits. The basic reason for the decrease in link performance with a decrease in entry angle can be attributed to the fact that the probe entry longitude moves further away from the sub-Earth longitude. This effect tends to reduce the link signal strength which results in a lowered data rate, and lowered descent time in which to conduct the mission. The shallow entry angle cut-off represents a 6000 total bit mission.

Relay Link

For a relay link mission, the nominal payload data transfer requirement of 27,000 bits can more than adequately be met by a TOPS flyby mission, TOPS J-U-N mission, and Pioneer F/G flyby mission. Relay link mission performance for these three missions is shown in Figure 18. These results are applicable for any opportunity and trajectory type since the angle between the approach velocity vector and the probe entry longitude which leads to a specific entry angle is invariant with opportunity and trajectory type. The relay link performance is sensitive to variations in planetary approach velocity. It was determined that for each of the three missions considered, the variation in approach velocity is sufficiently small to allow for use of a single mean value. Of the three missions studied, the TOPS flyby performance is superior simply due to the fact that the TOPS spacecraft relay link receiving antenna requirements can be satisfied by a high gain narrow beamwidth gimbaled dish. The spinning Pioneer F/G spacecraft, on the other hand, requires both a despun antenna, and considerably larger beamwidth requirements than the TOPS spacecraft. The lower data rate performance achievable by a TOPS J-U-N mission can be generally attributed to the constraints to flyby at the 6.8 planetary radii periapsis radius.

MISSION	FREQUENCY	TRANSMITTER POWER	DESCENT TIME
TOPS FLYBY	S	25 W	1.0 HR.
TOPS J-U-N	S	50	0.5
PIONEER F/G FLYBY	L	50	1.0

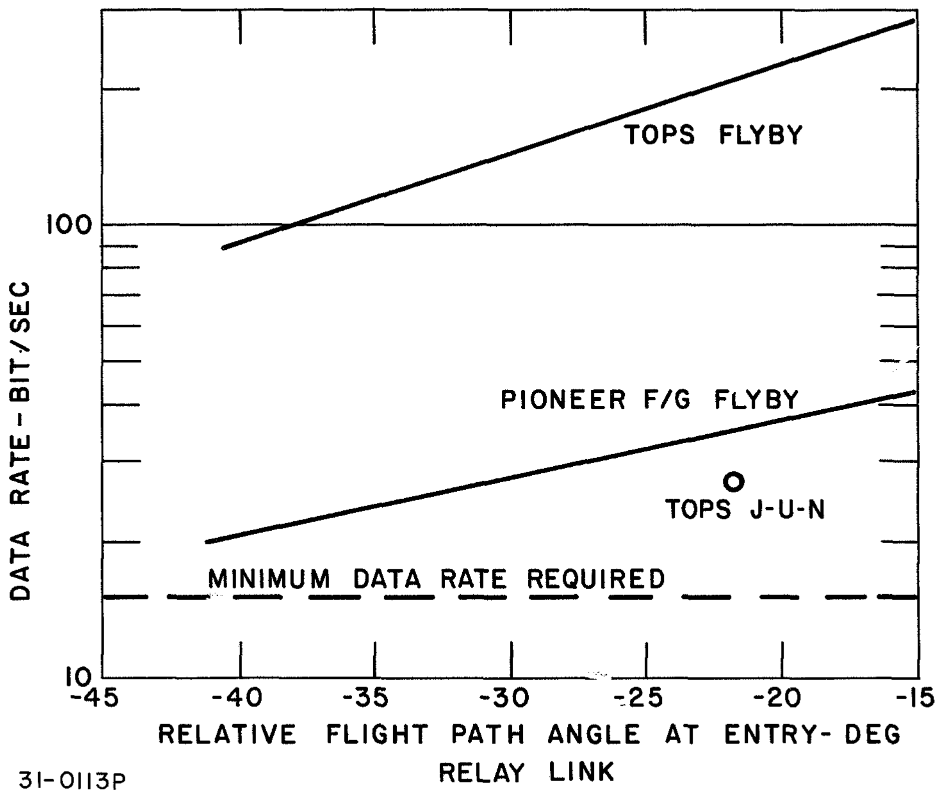

Figure 18 RELAY LINK COMMUNICATION PERFORMANCE

The results presented in Figure 18 show a trend of decreasing data rate capability with increasing entry angle. The two factors that lead to this trend are: 1) the location of the periapsis point on the planet, and 2) spacecraft lead time dispersions.

For steep entry angle missions, the probe descent longitudes are generally further displaced from the longitude at which the spacecraft makes its closest approach to the planet, therefore, resulting in increased communication range. Also it can be said the lead time dispersion, increases with steeper entry angles (mainly due from increased in plane ΔV errors) thus causing further link degradations due to increased antenna beamwidth requirements.

From the results presented in Figure 18, it can be said that relay link communication performance is consistent with other engineering factors which favors shallow entry angle missions. This, however, differs from the direct link results which favors steep entry angle mission in order to achieve improved communication performance.

4.5 SPACECRAFT SELECTION

Both TOPS and Pioneer F/G can serve as a bus for a Jupiter entry probe. In Table 7 there are indicated the important features for comparison. The spin-stabilized Pioneer F/G weight is considerably smaller than the weight of a three-axis stabilized TOPS. This weight differential is 900 lb. Adapter weights for the Pioneer F/G are greater due to the necessity of providing an adapter structure that carries the Pioneer F/G launch loads around the entry probe into the Burner II stage. In the case of the TOPS, the entry probe is not in the launch vehicle and spacecraft physical stack-up. Propulsion weight is

TABLE 7

COMPARISON OF TOPS AND PIONEER F/G SPACECRAFT

CHARACTERISTIC \ SPACECRAFT	TOPS	PIONEER F/G
UNMODIFIED SPACECRAFT WEIGHT	1450 LB	550
Δ WEIGHT OF ADAPTERS	32 LB	63
Δ WEIGHT OF PROPULSION	14 LB	44
RELAY ANTENNA GAIN	25 dB	17
RELAY ANTENNA WEIGHT	15 LB	24
SPACECRAFT POWER MARGIN	+60 W	+15

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also greater for the Pioneer F/G due to the fact that the entry probe substantially increases the spin moment of inertia of the spacecraft and the angular momentum. More propellant must be expended to precess the spacecraft. The relay antenna for the Pioneer F/G is electronically despun, as compared with the two axis gimbaled elliptical parabolic dish that is used on TOPS. These weight penalties for integration of an entry probe are greater for Pioneer F/G than TOPS, but these penalties do not overwhelm the basic spacecraft weight differential. The Pioneer F/G after probe integration is still substantially lighter in weight than the TOPS.

A higher performance relay link can be achieved with the gimbaled high gain antenna that can be adapter to TOPS. However, for the 1978 and 1980 flyby missions, the Pioneer F/G to probe data rates are satisfactory for the conduct of a adequate relay link communication link.

The margin of spacecraft power available for a relay link during encounter, is adequate. On the TOPS it will be necessary to relocate the thermal control louvers, move the magnetometer boom, and relocate the ACS thrusters mounted on the equipment compartment. For the Pioneer F/G it will be necessary to relocate the thermal control louvers, and extend the low gain antenna.

It has been assumed in this study that the precision in knowledge of attitude of the spacecraft at entry probe separation is the same for both Pioneer F/G and TOPS. This knowledge of attitude influences the subsequent entry probe dispersions in entry angle, communication range, and communication angle.

5.0 MISSION TRADEOFFS

Following the examination of the key science and key engineering tradeoffs, Jupiter Probe missions were identified and catalogued.

5.0 CANDIDATE JUPITER PROBE MISSIONS

A summary of candidate missions was generated based on consideration of launch opportunity, trajectory targeting, spacecraft, communication link, and lighting condition during entry. This summary, shown in Table 8, is based on use of the nominal payload, entry into the nominal atmosphere, and descent to the base of the cloud layers. Table 8 shows a qualitative evaluation of many missions. These missions are catalogued as: not applicable, not feasible, not of interest, feasible, and good.

The appellation not applicable applies only to use of Pioneer F/G for the 1979 Grand Tour mission. Grand Tour is an exclusive TOPS Spacecraft mission. Missions listed as not feasible require entry angles steeper than -50 deg. It was determined that at about -70 deg. entry angles, non-feasibility exists due to the fact that the available payload is reduced to zero, i.e. the aeroshell structural weights have consumed all available payload weight. The range in entry angle from -50 deg. to -70 deg. can be termed marginal, since the payload weight to gross entry vehicle weight is very small. For the purpose of this cataloging, no differentiation has been made between marginal and non-feasible missions. All the missions above -50 deg. entry angle are termed not feasible. Only nightside missions have been termed not of interest. If a shallow angle dayside mission was found, there did not appear to be any advantage to target for a less desirable nightside entry. The distinction between a feasible mission and a good mission is a relative one. The desirable features of a mission are: (1) short transfer time, (2) shallow entry angle, (3) long descent times, (4) small launch vehicle requirements, (5) large total bits

TABLE 8

CANDIDATE JUPITER PROBE MISSIONS

MISSION CLASSIFICATION		SPACECRAFT					
		PIONEER F/G			TOPS		
		RELAY		DIRECT	RELAY		DIRECT
		DAYSIDE	NIGHTSIDE	DAYSIDE	DAYSIDE	NIGHTSIDE	DAYSIDE
FLYBY	1978 TYPE I	3 FEASIBLE	GOOD	FEASIBLE	FEASIBLE	GOOD	FEASIBLE
FLYBY	1978 TYPE II	GOOD	NOT OF INTEREST	1 FEASIBLE	GOOD	NOT OF INTEREST	FEASIBLE
J-U-N GRAND TOUR	1979 TYPE I	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT FEASIBLE	2 FEASIBLE	NOT FEASIBLE
FLYBY	1980 TYPE I	FEASIBLE	GOOD	FEASIBLE	FEASIBLE	GOOD	FEASIBLE
FLYBY	1980 TYPE II	4 GOOD	NOT OF INTEREST	FEASIBLE	5 GOOD	NOT OF INTEREST	FEASIBLE

SELECTED SAMPLE MISSIONS

transmitted, (6) low entry probe weight, and (7) dayside entry. A feasible mission does not necessarily have to have any of these features, whereas a good mission tends to incorporate several of these desirable features. Five sample missions have been identified for further discussion in the next section. These missions have been numbered in Table 8.

5.2 SAMPLE JUPITER PROBE MISSIONS

The five sample missions were selected so as to cover the range of interesting mission options. The characteristics and performance of these sample missions is summarized in Table 9. Sample mission one is a direct link mission based on use of a Pioneer F/G spacecraft and a 1978 launch opportunity. Solar longitude is measured from the Jovian sub-solar point with positive being in the direction of rotation; a solar longitude of 90 deg. implies entry at the evening terminator. For a one-hour descent time, Jupiter rotates a total of 36 deg. If the solar altitude at the base of the clouds must be equal to or greater than 20 deg., then the solar longitude at entry must be equal to or less than +34 deg. This direct link mission satisfies the dayside mission since the solar longitude at entry is +8 deg. and the planet rotates 16 deg. during the 1600 sec. descent time; so that solar longitude at the termination of the mission, i.e. the base of the clouds, is 24 deg. Installed weight is defined as the entry probe weight plus the weight of the spacecraft subsystem additions and modifications. Launch vehicle weight is obtained by adding to the installed probe weight either 550 lb for Pioneer F/G or 1450 lb for TOPS. The booster configuration for sample mission one is a Titan III-D with two, five-segmented solid strap-on motors, an Agena third stage, and a Burner II fourth stage.

Sample mission two is an entry probe mission released from a Grand Tour flyby. Note that a relay communication link must be used for this entry probe that enters two degrees on the evening side of the terminator. The booster

TABLE 9

SAMPLE JUPITER PROBE MISSIONS

NOMINAL PAYLOAD, NOMINAL ATMOSPHERE, DESCENT TO CLOUD BASE

MISSION / CHARACTERISTICS	1	2	3	4	5
YEAR/TRAJECTORY	1978/II	1979/I	1978/I	1980/II	1980/II
SOLAR LONGITUDE AT ENTRY*, DEG	+8	+100	+50	+25	+25
SPACECRAFT BUS	PIONEER F/G	TOPS	PIONEER F/G	PIONEER F/G	TOPS
COMMUNICATION LINK	DIRECT	RELAY	RELAY	RELAY	RELAY
FLIGHT TIME, DAYS	1265	528	870	1350	1350
ATMOSPHERIC DESCENT TIME,** SEC	1600	1800	1800	3600	3600
ENTRY ANGLE, DEG	-33	-22	-33	-15	-15
BOOSTER CONFIGURATION	T5/A/B	T5/C/V	T7/C/B	T5/A	T5/A/B
INSTALLED PROBE WEIGHT, LB	770	572	803	596	508
TOTAL BITS TRANSMITTED	27,000	49,000	135,000	155,000	1,000 000

*MEASURED FROM THE JOVIAN SUB-SOLAR POINT WITH POSITIVE BEING IN THE DIRECTION OF ROTATION.
**SEPARATED PROBE WEIGHT PLUS WEIGHT OF ALL SPACECRAFT MODIFICATIONS TO ACCOMMODATE PROBE.

configuration for this mission is a Titan III-D with two, five-segmented solid strap-on motors, a Centaur third stage, and a Burner II fourth stage.

A 1978 Type I mission, sample mission three, was selected because it will allow for an early return of data. An entry probe that follows the mission profile of sample mission three will encounter Jupiter in February/March of 1982. The entry angle and descent time have been tailored so that a dayside mission can be accomplished with a Type I trajectory without resulting in step angle entry. For this mission, the launch vehicle is a Titan III-D with two, seven-segmented solid strap-on motors, a Centaur third stage, and a Burner II fourth stage.

Sample mission four was selected because it exemplifies a good, Pioneer F/G mission. It combines shallow entry angle, long descent time, large data output, and small launch vehicle requirements.

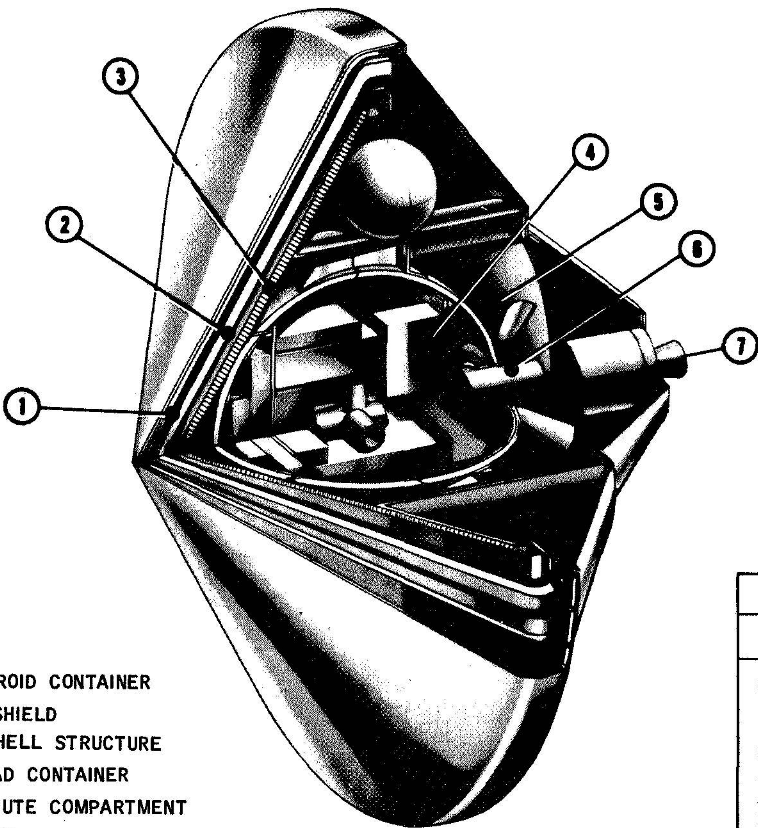
Sample mission five is a good, TOPS spacecraft mission. The transmitted bit potential of the mission is very large, and the mission can be accomplished with the use of a medium-size launch vehicle.

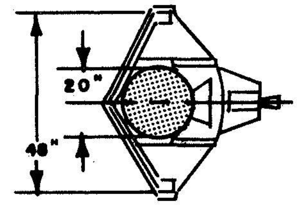
6.0 SYSTEM AND SUBSYSTEM CONFIGURATIONS

The system and subsystem descriptions that are provided in this section were used to generate the parametric design data that was presented in Section 5.0.

6.1 SAMPLE JUPITER ENTRY PROBE CONFIGURATION

A typical entry probe configuration is shown in Figure 19. The nominal payload is packaged within a 20 inch diameter pressure vessel that is designed to resist the pressure associated with the base of the Jupiter clouds (17 atm in the nominal model atmosphere). An internal pressure, slightly in excess of one atmosphere is provided by a gas like sulfur hexaflouride. This gas is added to both inhibit voltage breakdown and to provide a good heat transfer media between the several subsystems. External to the pressure vessel is a layer of Min-K insulation that retards the flow of heat from the atmosphere into the payload. This external insulation plus the internal phase change salts that are packaged with the payload, limits the temperature excursion during descent to a range of +60 by F to + 160 deg F. This payload, pressure vessel, and insulation subsystem is packaged within a 60 deg. (half angle) cone. An aeroshell diameter of four feet was selected since this dimension resulted in the location of the entry probe center of gravity at the maximum diameter. Static stability requirements are satisfied since the center of pressure of a 60 deg. cone is aft of the maximum diameter of the entry probe.





PROBE WEIGHT AT SEPARATION	
SUBSYSTEM	WEIGHT – LB.
SCIENCE	42
ELECTRICAL	35
ENVIRONMENTAL	71
SEPARATION	25
AUX STRUCTURE	25
AEROSHELL STRUCTURE	34
HEAT SHIELD	120
TOTAL	352

1. METEOROID CONTAINER
2. HEAT SHIELD
3. AEROSHELL STRUCTURE
4. PAYLOAD CONTAINER
5. PARACHUTE COMPARTMENT
6. ANTENNA
7. PROPULSION MODULE

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Figure 19 JUPITER ENTRY PROBE CONFIGURATION

A titanium honeycomb aeroshell is provided to resist the aerodynamic pressure loads, and a high density ablator/low density insulator composite heat shield provides thermal protection. A parachute is packaged around the entry probe afterbody. The entry probe is enveloped by a container that provides protection against the meteroid hazard. To this container is attached a propulsion system used to deflect the entry probe from a flyby of Jupiter onto an impact trajectory. Also attached is an RTG which provides electrical energy for checkout and thermal heat energy for thermal control during the post separation cruise. Entry probe characteristics are tabulated in Table 10.

6.2 SAMPLE ENTRY PROBE/SPACECRAFT CONFIGURATIONS

A TOPS and entry probe configuration is shown in Figure 20. An elliptical relay antenna with a two axis gimbal is mounted on the spacecraft in place of the medium gain X-band antenna that is gimbaled about one axis The elliptical antenna is a dual function antenna. It serves as: 1) a high S-band gain receiving antenna for the probe to TOPS relay link, and 2) with the addition of an offset feed that illuminates a quarter portion of the dish, it is used as an X-band antenna in a medium gain mode for the TOPS to DSN downlink. The antenna dimensions are 31 x 41 inches, and the peak gain is 25 dB. A 48 inch diameter probe is shown mounted to the equipment compartment.

A Pioneer F/G and entry probe configuration is presented in Figure 21. The entry probe is mounted along the Pioneer F/G longitudinal axis. An electronically despun, L-band circumferential antenna is utilized to provide the high gain requirements. A photometer must be provided or an output from

TABLE 10

ENTRY PROBE CHARACTERISTICS

SHALLOW ENTRY ANGLE, NOMINAL ATMOSPHERE, NOMINAL PAYLOAD

SUBSYSTEM	FUNCTIONAL REQUIREMENTS	CHARACTERISTICS
SCIENCE	ACHIEVE SUBSONIC VELOCITY ABOVE CLOUDS NOMINAL PAYLOAD	48 INCH DIA 60 DEG SHARP CONE AEROSHELL ACHIEVES 0.7 M AT 77 MB WITH -15 DEG ENTRY ANGLE AND 0.48 SLUG/FT^2 M/CDA
COMMUNICATION	100 BIT/SEC RATE RELAY LINK PERFORMANCE MARGIN EQUAL TO OR GREATER THAN SUM OF ADVERSE TOLERANCES	S BAND 50 W TRANSMITTED POWER CONICAL REFLECTOR: 4.7 dB AT HALF POWER BEAM WIDTH OF 44 DEG
POWER	232 W FOR 5400 SEC	860 WH-HR OF SILVER-ZINC BATTERIES
DATA HANDLING	SAMPLE INSTRUMENTS, FORMAT DATA, ENCODE, CLOCK AND TIMER, PROGRAMMER AND CHECKOUT	LOW POWER, SOLID STATE/HYBRID ELECTRONICS
PRESSURE VESSEL	MAXIMUM OPERATING PRESSURE, 17 ATM MAXIMUM OPERATING TEMPERATURE, +425 DEG F	TITANIUM MONOCOQUE SPHERE (.07 INCH WALL)
TEMPERATURE REGULATION	ATMOSPHERIC DESCENT TIME, 3600 SEC DISSIPATED POWER DURING DESCENT, 340 W-HR MAXIMUM PAYLOAD TEMPERATURE, 160 DEG F MINIMUM PAYLOAD TEMPERATURE, 60 DEG F	0.4 IN MIN-K INSULATOR 10 LB OF PHASE CHANGE MTL (MELT TEMP, 97 DEG F) 22 W OF RTG THERMAL POWER (POST SEPARATION)
STRUCTURE	ENTRY VELOCITY, 160,000 FT/SEC FLIGHT PATH ANGLE AT ENTRY, -15 DEG AXIAL LOAD, 525 G STAGNATION PRESSURE, 8 ATM	TITANIUM HONEYCOMB (.04 INCH FACE SHEETS, 0.5 INCH CORE)
HEAT SHIELD	MAX HEAT RATE, 20,000 BTU/FT^2 - SEC INTEGRATED HEATING, 71,000 BTU/FT^2	GRAPHITE ABLATOR (0.5 INCH THICK) LOW DENSITY CARBONACEOUS INSULATOR (1 INCH THICK)
PROPULSION	164 FT/SEC FOR DEFLECTION	END BURNER ROCKET MOTOR, 1700 LB-SEC
PARACHUTE	EXTRACT PAYLOAD CONTAINER AT 0.7 M	20 FT D_0 NYLON CHUTE, DYNAMIC PRESSURE AT OPENING, 60 LB/FT^2
ATTITUDE CONTROL	CONTROL SPIN RATE TO ENTRY POINT NULL ANGLE OF ATTACK	HYDRAZINE PROPELLANT, SIX THRUSTERS, NITROGEN PRESSURANT

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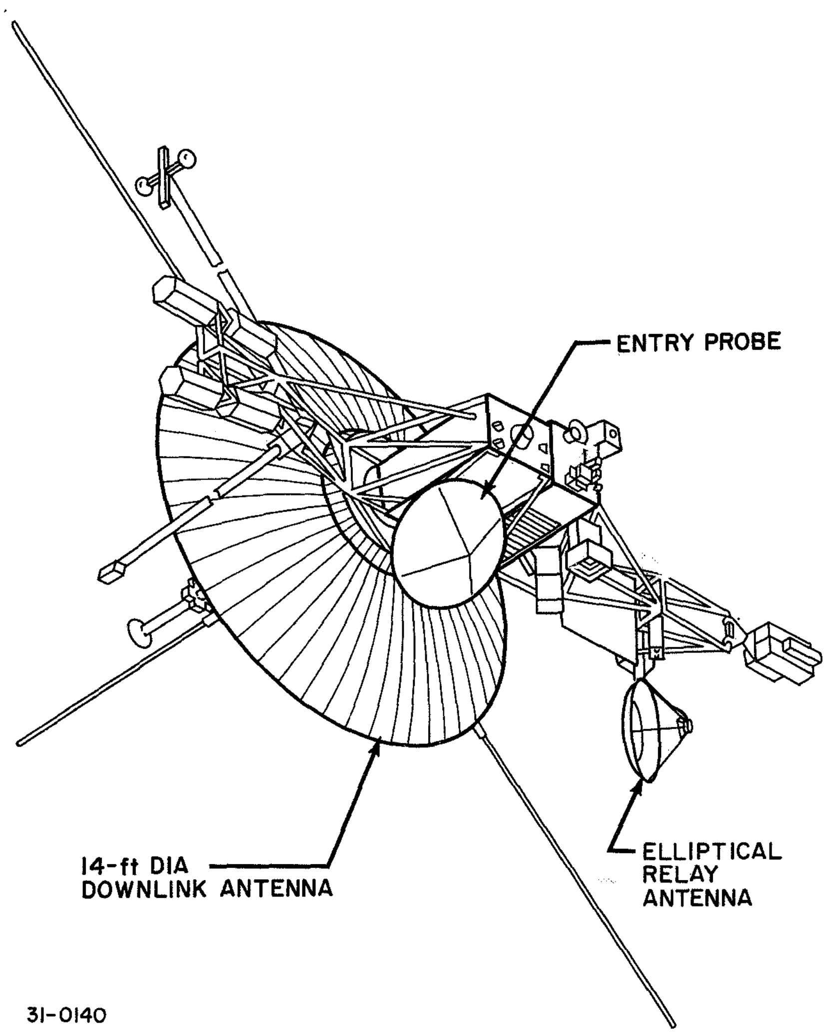

Figure 20 TOPS/ENTRY PROBE CONFIGURATION

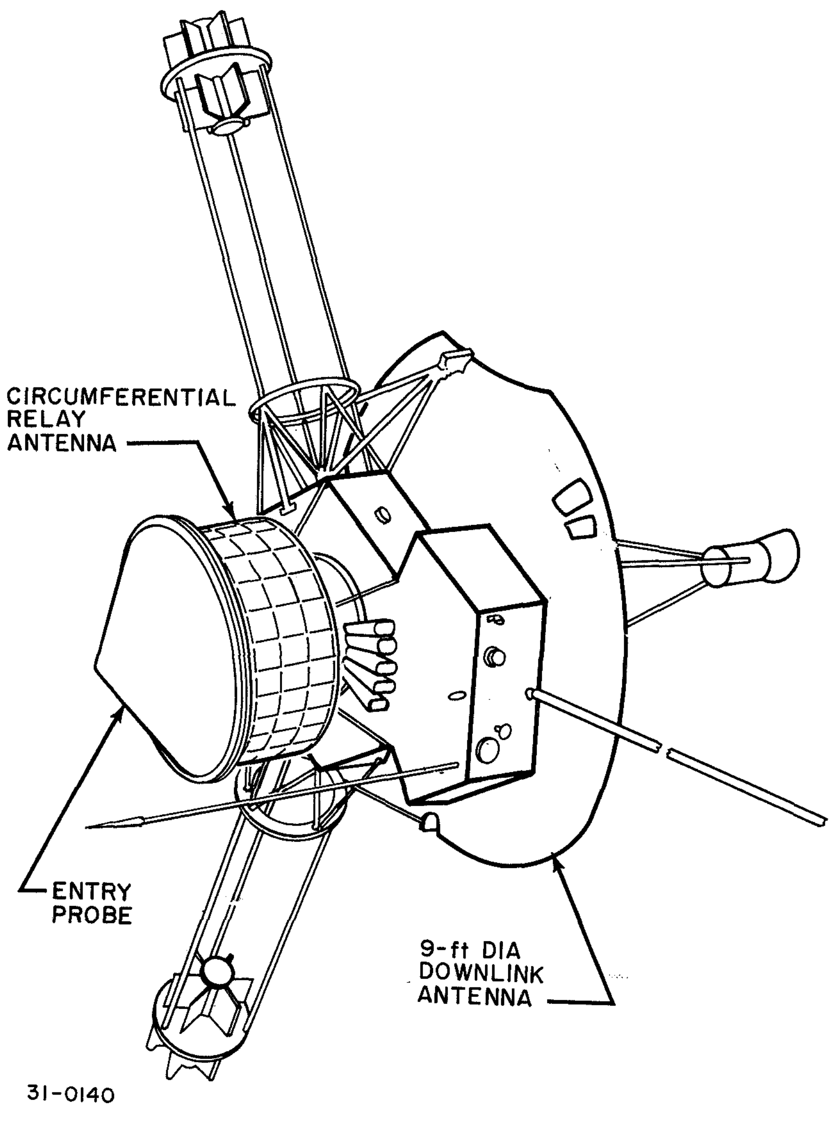

Figure 21 PIONEER F/G ENTRY PROBE CONFIGURATION

the spacecraft encounter sensors must be provided to switch the proper antenna elements to enable high gain operation in the direction of the planet. This antenna is mounted to the half of the flight vehicle to the Burner II adapter that remains with the spacecraft after separation. This circumferential antenna array has a diameter of 50 in., a length of 14 in., and a 17 dB gain.

A weight summary of the entry probe with TOPS and Pioneer F/G. is shown in Table 11. It can be seen that the weight differential between the TOPS and Pioneer F/G is 900 lbs. The weight differential between the launch vehicle weights of TOPS and Pioneer F/G with an entry probe is almost 800 lb. Although the spacecraft support subsystem weights for a Pioneer F/G is greater than that for TOPS, these larger support subsystem weights do not substantially change the weight advantage of Pioneer F/G.

TABLE 11

JUPITER ENTRY PROBE FLIGHT VEHICLE WEIGHTS

ELEMENT	SPACECRAFT, LB	
	TOPS	PIONEER F/G
ENTRY PROBE AT SEPARATION	352	352
SPACECRAFT SUPPORT	72	145
ADAPTERS	32	63
RELAY COMMUNICATIONS	26	38
PROPULSION	14	44
INSTALLED PROBE	424	497
CONTINGENCY (20%)	84	99
SPACECRAFT	1450	547
FLIGHT ARTICLE	1958	1143

7.0 JUPITER ENTRY PROBE TECHNOLOGY REQUIREMENTS

The technology requirements were identified following study of the key science tradeoffs and key engineering tradeoffs, which led to mission tradeoffs and selection of numerous candidate missions, and subsequent description of entry probe system and subsystem configurations. These technology requirements have been catalogued into three classes and are described herein.

7.1 RESEARCH REQUIREMENTS

A research requirement is defined as an area of improvement that is associated with the physical parameters of Jupiter. Three research requirements have been identified.

Improvement in the assessment of the model atmosphere range - An assessment of the Jovian model atmospheres has indicated that the cool/dense model atmosphere has the most severe influence on the entry probe design. Consideration of the cool/dense model atmosphere results in the need to qualify the subsystems in a high G environment, provide a pressure vessel to resist very high pressure, and provide a heavy aeroshell structure. All of these factors combine unfavorably and result in a low payload to total probe weight fraction. A direct link and use of S-band operating frequencies is not feasible. A better definition of the atmosphere uncertainty that tends more towards the nominal atmosphere would ease the probe development problems and improve the efficiency of the design.

Development of atmospheric wind and turbulence models - It is necessary to develop atmospheric wind and turbulence models to provide meaningful design criteria. During the conduct of this study, this model information was not available. Winds and turbulence cause probe attitude disturbances which, in turn, are reflected in the requirement of wider antenna beam widths or use of steered antenna concepts. In addition, atmospheric turbulence can induce refractive index fluctuations which scatter radio frequency waves and lead to signal fading.

Improvement in the Jovian ephemeris -- The entry probe, while attached to the spacecraft, is on a flyby of Jupiter. The probe must be separated from the spacecraft, maneuvered to a specific attitude so that the rocket motor is oriented in the proper direction, and a deflection impulse added to place the probe onto an impact trajectory. Three separation error sources contribute to the error in entry angle and error in lead time. Lead time is defined as the difference in time between the probe achievement of atmospheric entry and the spacecraft achievement of periapsis passage. The separation error sources are: impulse uncertainty of the deflection rocket motor, attitude uncertainty of the probe orientation subsystem, and ephemeris uncertainty in the location of Jupiter. For shallow angle targeting the principal contributor to the error in entry angle is the ephemeris uncertainty.

7.2 CRITICAL TECHNOLOGY REQUIREMENTS

A critical technology requirement is defined as an area of improvement that is associated with the engineering feasibility of the entry probe. Four critical technology requirements have been identified.

Calculation and simulation of ablator response to heat probe --The effectiveness of the heat shield to block aerodynamic heating and the characteristics of heat shield removal present the greatest engineering uncertainty in the design of an entry probe. The aerodynamic heating environment associated with entry at 49 Km/sec is well beyond the current state-of-the-art in ground test and flight test simulation. At present, the thermal protection system requirements for a Jupiter probe have been based on use of analytical models.

Since these results are not supported by test data, they are considered conjectural. The symmetry of removal of ablator and the momentum imparted during ablator removal influence the dynamical motions, and can cause extreme changes in entry probe angular rates. Anticipation of extreme dynamical motions would lead to the requirement of provision of an active control system through entry. It should be pointed out that the need for test is based on an approach that tends to improve the chance for success of a single mission but also creates some difficult simulation problems. Another approach would parallel the Soviet approach to Venus exploration. A long-term commitment can be made to Jovian exploration, and every thirteen months a probe is launched until success is achieved. Such an approach tends to reduce the requirement for a thorough simulation, but it also reduces the chance for a successful mission on a given flight.

Development of subsystems to survive high-G environment-- Prior to entry the probe subsystems will be turned on. During entry, accelerometer data will be collected and stored for retransmission following emergence from communication blackout that is associated with entry. A G level of 525 is associated with shallow angle entry into the nominal model atmosphere. At present, some work has been initiated on qualification test of Venus entry probe subsystems. Maximum G for Venus entry is about 400, and using a 50 percent greater qualification test specification will result in test at 600 G. This qualification test for a Jupiter probe will be 750 G or greater.

Assessment of system performance in a high gamma field -- Passage through a magnetic field some thirty-fold greater than the Earth's magnetic field can result in probe despin and probe attitude perturbations during post separation flight prior to entry, loss of magnetic core storage data, and induction of spurious voltages in the instrumentation subsystems. Despin and attitude perturbations can be corrected by introduction of an attitude control system. Envelopment of the magnetic core memory with a high permeability cover can shield against magnetic field effects. The combination of shorter leads oriented along the velocity vector or magnetic field lines and the use of twisted-shielded pairs and differential amplifiers can all reduce the influence of the magnetic field.

Development of subsystems with long shelf life -- The transit time for a Type II trajectory can be as long as four years. During this period, the entry probe subsystems will remain dormant except for possible periodic checkout. At present, subsystems for Pioneer F/G are being developed with specifications that call for a two to five year life, and work has been initiated on TOPS subsystems that must have a reliability of performance that is consistent with a five to twelve year lifetime.

7.3 KEY TECHNOLOGY IMPROVEMENT AREAS

A key technology requirement is defined as an advance in the state-of-the-art of a subsystem that will provide greater mission flexibility and/or performance.

Improvement in aeroshell structure strength to weight ratio -- Present aeroshell structure design is based on use of titanium honeycomb construction. It was determined that with this type of construction that entry at angles steeper than about -70 deg. was not feasible. Advancement in structural design can remove this restriction or move it closer to vertical entry. In general, any advancement in structural design would decrease the structure weight and improve the payload to total entry probe weight fraction.

Reduction of dispersion in impulse of deflection motor -- Lead time errors are most sensitive, for steeper entry angle targeting, to errors in the application of impulse. Dispersions in communication range and communication angle that influence the performance of the relay link are related to lead time dispersion.

Reduction of dispersion in probe guidance -- Lead time errors are most sensitive, for shallow entry angle targeting, to errors in the deployment angle.

Assessment of radio frequency attenuation by Jovian atmosphere -- The work in this present study of RF radio frequency is based on theoretical analysis. It will be necessary to obtain measured data based on the best estimates of the model atmospheres to improve the confidence of the link design.

Development of lightweight steerable antenna arrays; development of higher power more efficient transmitters -- Both of these developments combine to provide a greater available power gain product, and will allow for greater transmission of data and/or allow greater targeting flexibility.

8.0 STUDY CONCLUSIONS

There are three major study conclusions. These are: (1) many feasible missions exist, (2) use of remote sensing with radiometers from the base of the clouds in combination with direct sensing during passage through the clouds can be used to achieve the science objectives, and (3) research and development must be pursued to improve probe efficiency and to enhance mission success.

Many feasible entry probe missions have been found for 1978 and 1980 flyby missions and for a 1979 Jupiter - Uranus - Neptune Grand Tour mission. Both TOPS and Pioneer F/G can be used as a bus for an entry probe. Dayside missions offer more advantageous science measurements, but that a nightside mission will result in achievement of the science objectives. Both direct and relay communication links are feasible, but that a relay link offers the opportunity of targeting for a shallow entry angle.

Qualitative evaluation of the ability of a probe that descends and survives to the base of the cloud layers to achieve the science objectives has indicated that the concept is feasible. It was determined that the science objectives concerned with cloud structure, organic matter, and coloring matter are automatically satisfied by a probe that descends to the base of the clouds. Atmospheric composition determination can be substantially determined, i.e. except for compounds of the heavy elements which are involatile at the relatively low cloud temp eratures. Knowledge of the thermal structure to the base of the clouds is determined since the probe is designed to survive to this level. Thermal structure below the clouds is determined by measuring the microwave brightness temperature. A lapse rate is inferred from the remote brightness temperature and coinc dent in situ temperature, pressure, and composition measurements. Knowledge o the lapse rate provides the piece of information needed to determine whether radiation transport, conversion transport, or convection transport carries thermal energy from the interior to the upper atmosphere.

Research and development can be used to reduce the dynamic range of probe design, and to improve the science return or reduce the engineering risks. Certain areas like: heat shield response to the aerodynamic heating, subsystem survival after exposure to a high-G environment, system and subsystem response to a high gamma field, and long shelf life subsystems are considered critical technology requirements and are amenable to immediate study. In general, meaningful research and development can be pursued based on current understanding of probe mission and configuration requirements.